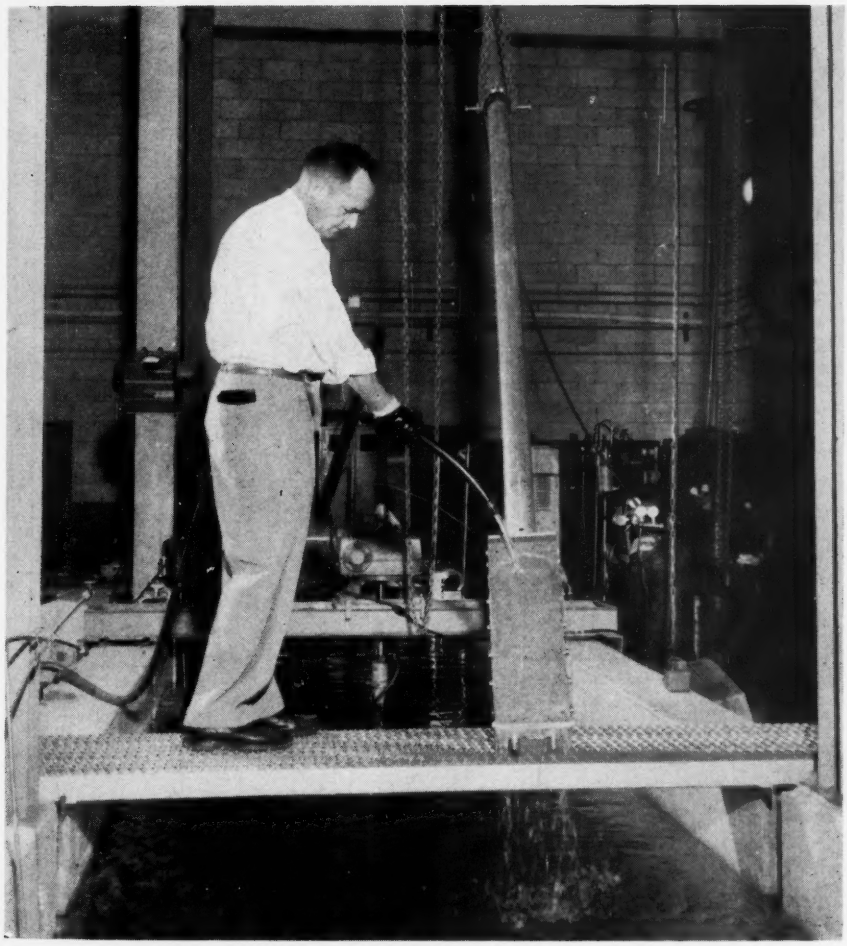
July, 1958

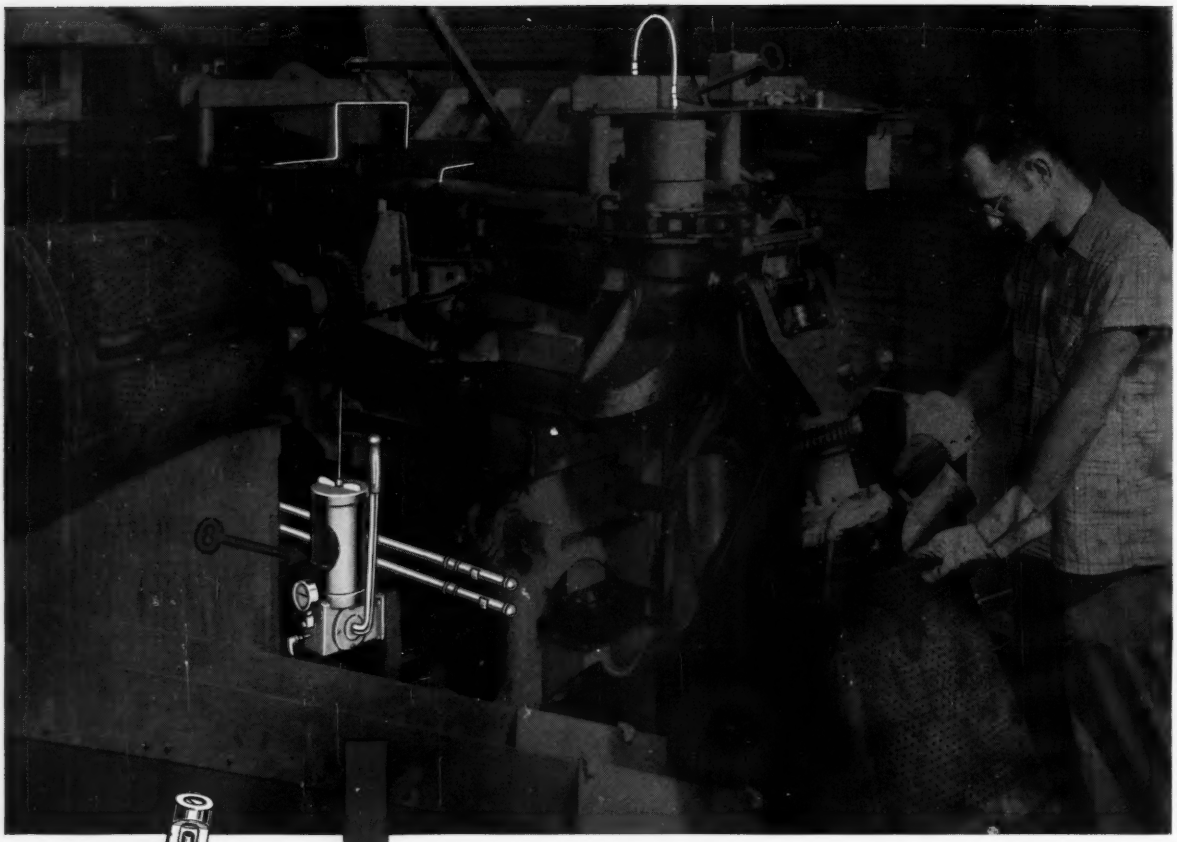
LUBRICATION ENGINEERING

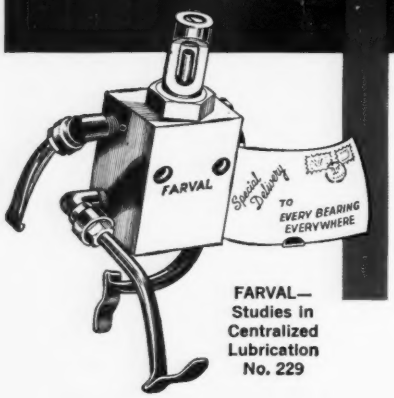
DESIGN APPLICATION RESEARCH EDUCATION MAINTENANCE



Radiation Stable Greases . . . p. 292

JOURNAL OF THE AMERICAN SOCIETY OF LUBRICATION ENGINEERS





FARVAL—
Studies in
Centralized
Lubrication
No. 229

Farval cuts downtime on automatic plating machine

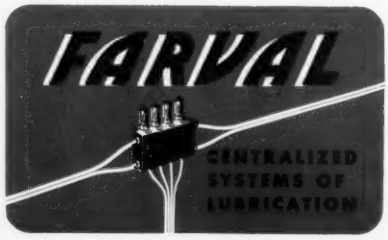
Quantity production is a prime purpose for automatic machines such as this Stevens plater. Bearing failure, long the enemy of automatic processes, is eliminated on this plating machine at a prominent Midwestern automotive parts plant through application of a Farval lubrication system. Downtime for repair of bearings is virtually eliminated.

This Farval system provides measured amounts of lubricant to each bearing at regular intervals. Large ports on Farval systems insure adequate lubrication without dangerous line pressure loss or grease separation.

Learn how you can cut downtime with an application of a Farval system to your process or machinery. Ask for revised Bulletin 26-S. Write The Farval Corporation, 3267 East 80th Street, Cleveland 4, Ohio.

KEYS TO ADEQUATE LUBRICATION

—wherever you see the sign of Farval—familiar valve manifolds, dual lubricant lines and central pumping station—you know a machine is being properly lubricated.



Affiliate of The Cleveland Worm & Gear Company, Industrial Worm Gearing. In Canada: Peacock Brothers Limited.

LUBRICATION ENGINEERING

DESIGN RESEARCH APPLICATION EDUCATION MAINTENANCE

Volume 14, No. 7

July, 1958

Contents

LUBRICATION IN PRACTICE

Greases Stable to Radiation under Dynamic Conditions.....292
J. R. A. Handschy, J. W. Armstrong, and B. E. Gordon

DESIGN, RESEARCH, DEVELOPMENT

The Effect of Pressure and Molecular Weight Upon the Viscosity of Polybutenes.....298
L. B. Sargent, Jr.

A Radiotracer Approach to the Study of Engine Valve Train Lubrication.....302
M. J. Furey and J. F. Kunc, Jr.

Radiotracer Study of the Effect of Lubricants on Metal Transfer in Drawing Brass.....310
C. Fisher, A. Shapiro, S. Berk, M. Petronio, L. Teitell, and H. Gisser

CURRENT NEWS

ASLE News Notebook.....289
Personals.....285
Section News.....288

FEATURES

Editorial.....301
Lube Lines.....287

LITERATURE SUMMARIZED

Literature Abstracts.....282
Patent Abstracts.....319
Book Review.....288

TRADE INFORMATION

Advertisers' Index.....320
New Products.....283
Product Literature.....316

Staff

John Boyd, Editor
Vera Blake, Editorial Production
A. F. Brewer, Consulting Editor
C. L. Willey, Business Manager
R. D. McCormick, Editorial Consultant

ASLE Publications Committee

D. W. Sawyer, ALCOA Research Laboratories, Chairman
John Boyd, Westinghouse Research Laboratories
J. Willard Peterson
Standard Oil Co. (Indiana)
C. A. Tomczak
C. L. Willey

Editorial Review Committee

John Boyd, Chairman
W. E. Campbell, Afram Consultants
R. K. Gould, Beacon Laboratories, Texas Co.
A. A. Raimondi, Westinghouse Research Laboratories
E. E. Bisson, NACA
John Givens,
Ernest Rabinowicz, MIT
M. C. Shaw, MIT
L. B. Sargent, Jr., ALCOA Research Labs.
H. W. McCulloch, Jr., Shell Oil Co.

Publishers Representatives

Eastern Region

ASLE
84 E. Randolph Street
Chicago 1, Illinois
DEarborn 2-1298

Central Region

DWIGHT EARLY & SONS
100 N. LaSalle St.
Chicago 2, Ill.
CEntral 6-2184

Western Region (15 states)

McDONALD-THOMPSON
San Francisco 5, Calif.
625 Market Street
YUkon 6-0647

Los Angeles 5, Calif.
3727 W. Sixth Street
DUnkirk 7-5391

Seattle 4, Washington
1008 Western Avenue
ELliot 3766

Denver 2, Colorado
Colorado Nat'l Bank Bldg.
KEystone 4-4669

Houston 6, Texas
3217 Montrose Blvd.
JA 9-6711

Tulsa 4, Oklahoma
2010 South Utica
RIverside 3-1981

Abstracted by Engineering Index and Industrial Arts Index

LUBRICATION ENGINEERING is published monthly by the American Society of Lubrication Engineers, 84 E. Randolph St., Chicago 1, Illinois. Current volume single copies 75¢. Copies of issues from previous volumes $1.00, if available; Copies to Foreign addresses add 50¢ per copy. Annual Subscription $6.00 in the USA and Canada, $7.00 to all other countries.

Copyright 1958 by the American Society of Lubrication Engineers. ASLE will not be responsible for statements or opinions presented at its meetings or printed in its publications.

Second class mail privileges authorized at Chicago, Ill.

Selected literature compiled by members of the Technical Committees and Industry Councils of the Society

Literature Abstracts — W. E. Campbell, Editor

Anon., "Scuffing Tests for Gear Oils," *J. Inst. Petroleum,* **v. 43 no. 404, 1957, 230-32.**

This describes a tentative standard method, IP166/58T, for the load-carrying capacity of gear oils (steel on steel) using IAE 3¼-inch centers gear machine. The test is run in steps of five minutes run and five minutes rest, with load increased by 305 pounds per inch width of gear for each run. The gears have hunting teeth; the dimensions are stated. Criterion for failure is scuffing or scoring on both approach and recess portions of the teeth. Four tests are required for one lubricant. No instructions are given for choosing conditions, which may be either 2000 rpm, 140°F; 4000 rpm, 158°F; or 6000 rpm, 230°F. This test is not intended to rate worm-gear or hypoid lubricants. (*Abstracted by E. A. Ryder.*)

L. Raymond, "New Horizons with New Gear Lubricants," Soc. Aut. Eng. paper no. 161 for meeting August 12-16, 1957.

Higher horsepower and increased low-gear ratio in automatic transmissions have resulted in several-fold increases in axle gear loading in both passenger cars and commercial vehicles. Lubricants and lubrication have become a limiting factor in axle performance, and single-purpose factory-fill lubricants and the older multi-purpose lubricants have not kept pace with the new requirements. Extensive research by lubricant and additive manufacturers has resulted in a new type of multi-purpose gear lubricant possessing the antiscoring advantages of active-sulfur-type characteristics of more inactive type products. The performance of the new type gear lubricants has been proven in extensive tests in different types of vehicles under a variety of severe operating conditions. New axle test methods have been developed for incorporation in an upgraded version of Specification MIL-L-2105. The development of a Reference Gear Lubricant Scale accompanying this work has facilitated evaluation of axle requirement levels and lubricant quality levels. The new-type products have been designated by Industry as "Multipurpose-Type Gear Lubricant for API Service GL-4." The advantages of the new products to civilian users and the Military are covered. Continuing problems arising principally from the trend to higher temperatures and the need for continuing cooperative effort are described. (*Abstractor: L. W. Manley.*)

J. Pawlowski (Farbenfabriken Bayer, Leverkusen, Germany), "Rotary Viscometer for Measuring Torsional Moments Without Displacement," *Chem. Ing. Tec.* **v. 28, no. 12, 1956, 786-93 (In German.)**

A rotational viscometer in which the microtorsion produced in a rod by the torsional moment of the sample is converted into electronic impulses is superior to conventional instruments based on deflection or compensation techniques, for studying rapid thixotropy and rheoplastic materials, and studying relaxation phenomena in gel-like substances. For a 0.86 mm measuring slot, the range of deformation velocities which can be continuously controlled is about 0.2-900/sec, and the smallest shear stress which can be measured is about 10 dynes/cm². The operation of the instrument and its application to various types of materials, including silicone oils, are described. (*Abstractor: E. O. Forster.*)

W. E. Klein (Evinrude Motors, Milwaukee, Wisc.), "Clean, Cool, Cutting Oil Permits Better Grinding." *Machinery,* **October, 1957, 154-56.**

Specific conditions are given for maintaining hardness and close tolerances for pin and main bearing surfaces of Evinrude outboard motor crankshafts. The conditions given for producing a fine ground finish (10 microinches) on steel, are of general interest. A 130 sec mineral-lard oil with 0.5 percent sulfur is substituted for a water soluble coolant. Very important is the addition of a continuous automatic feed roll cloth filter and a refrigeration unit which maintains the oil at the flow pipe at room temperature. Filtration removes the chips to reduce wheel loading and the frequency of wheel dressing, in addition to improving finish from 20 to 10 microinches. (*Abstractor: N. C. Morrell.*)

L. H. Butler (Univ. Wales, Cardiff) "Lubrication—A Study of its Action in Continuous Metal Deformation. Part I," *Steel Processing & Conversion,* **v. 43, no. 5, 1957, 269-75.**

Data are presented from a survey of literature, which aids in overcoming aluminum-rolling problems and improve understanding of the mechanism of friction and lubrication during continuous metal deformation.

After a summary of the mechanism of friction according to several sources, and choice of the welding-of-metal theory of friction as most universally accepted, that theory, together with the position of the shear plane as influencing metal pick-up, are discussed. Temperature rise at contacting points influences the amount of metal transfer and wear. Coefficient of friction is not as important as surface conditions and welding of metal in continuous metal deformation.

A review of the several types of lubrication follows: hydrodynamic and hydrostatic (both full flow); boundary lubrication; extreme pressure (metallic chlorides and/or sulfides) which is not used much in metal deformation; solid lubricants (talc-mica-lime) which have high melting points and low sheer strength, but are not generally used.

Requirements of lubricants in metal deformation processes are: elimination of metallic contact and reduction of the coefficient of friction between the tool (sic) and the material. In rolling aluminum, if rolls and strip are moving at the same peripheral speed at neutral plane, high frictional heat develops and may affect the lubricant and the metal surface. The lubricant must wet rapidly and cover freshly exposed metal. Low limit for coefficient of friction is exceeded when slab refuses to enter rolls or when rolls slip continuously. Elimination of welding and lowering coefficient of friction to bring power economy have to be balanced with surface desired on the finished aluminum strip.

Requisites for lubricants in specific jobs include: resist thermal breakdown; tenacious adherence; non-staining; low viscosity; high flash; non-toxicity; high specific heat. Here again a compromise must be effected to meet conditions imposed by the job being done. (*Abstractor: N. C. Morrell.*)

(*Continued on p. 284*)

New Products

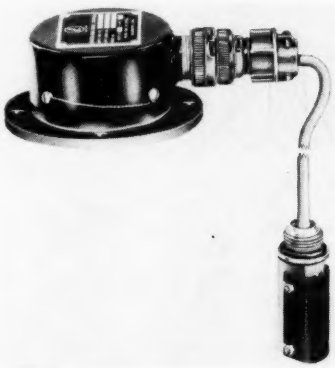
MULTIPURPOSE E-P GREASE RELEASED AFTER TWO YEARS OF FIELD TESTS

A calcium E-P complex grease chemically stable from −15 to +300° F with water resistant properties has been released for industrial use. Field testing conditions included dry, hot, cold, high-speeds, extreme pressures, and foreign contaminants for both plain and rolling contact bearings.

Product is marketed under the name Mobilplex EP. Further information may be securred from Socony Mobil Co., Inc., 150 E. 42nd St., New York 17, N. Y.

LIQUID LEVEL INDICATED OR CONTROLLED BY OPTICAL SYSTEM

Optical level indicator delivers 10 amperes for indicating or controlling liquid levels. Incorporating a photoelectric level-sensing probe, the unit operates on the principle of total internal reflection rather than the transmission of light through the fluid medium. Power may be applied to indicator lamps, pumps, valves, etc., with operation in milliseconds. Repeatability is within 0.015 inch, and unit is claimed to be unaffected by shock, acceleration, altitude or foam, and can distinguish between airflow and fluid flow when installed in a line. Unit may be used or modified for use with any fluid compatible with the stainless steel probe housing regardless of opacity.

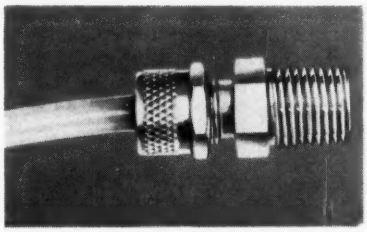


Probe temperature range is −65 to +250° F. Unit meets MIL-F-8615(ASG) and MIL-E-5272B requirements.

Optical Level Indicator is manufactured by Revere Corporation of America, Wallingford, Conn.

FITTINGS FOR GLASS OR PLASTIC FORM LEAKPROOF SEAL

Newest addition to the line of tube fittings, designed for connections on glass and plastic tubing, are recommended for hard to reach installations. Assembly and disassembly of fitting, utilizing knurled nuts, is quick, and can be made without tools. Finger tightening of nut provides leak-proof seal. Wrench pad permits use of wrench for tighter seals.

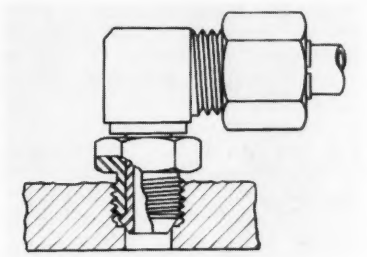


Stocked in sizes from 1/16 to 1 inch OD tube, swagelock fittings and recommendations for their application can be secured from Crawford Fitting Co., 884 East 140th St., Cleveland 10, Ohio.

STRAIGHT THREAD DESIGN PERMITS CLOSE MOUNTING OF HYDRAULIC PORT FITTINGS

Designed to replace conventional pipe thread or O-ring fittings, a new hydraulic fitting consisting of a swivel body and a floating threaded nut, which turns freely on a stem of the body, has been announced.

Floating nut is inserted into threaded port which has been seated with step drill or counterbore. No special finishing of seat is required. As nut is turned, it bears against a step at bottom of the stem forcing end of the stem against the bottom of hole. Conical end of stem seats forming metal-to-metal seal. Nut may be turned without turning the body, no swing clearance is required, and connection may be broken without disrupting connecting lines.



Space savings from new fitting permit, for example, mounting ½ inch fittings on one inch centers with adequate clearance for assembly.

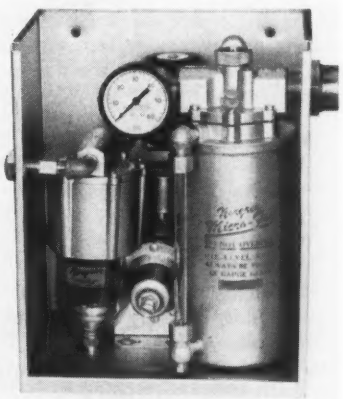
Flodar metal-to-metal seal can be obtained in all conventional shapes in sizes ranging from ¼ to 2 inches OD. Catalog M-57, with detailed information is available from the Flodar Corporation, 16911 St. Clair Ave., Cleveland 10, Ohio.

FOG LUBRICATION UNITS AVAILABLE IN TAMPER-PROOF CABINETS

Unauthorized personnel will be unable to tamper with adjustments on fog lubrication units enclosed in splash-proof cabinets. Units are available with choice of 32, 200, or 300 rated bearing-inch capacities and reservoirs containing one or two quart oil capacities.

Standard for all models are (1) 25-micron air filter which automatically removes liquids and solids from the air supply and automatically drains collected moisture, (2) solenoid valve which automatically starts and stops lubrication as machine power is turned on and off, (3) pressure regulator to reduce main line air pressure to the desired working pressure and hold it constant, (4) pressure switch to actuate an alarm or shut down machine if air pressure fails, and (5) fog lubricator which delivers a controlled amount of air-borne lubrication to all bearings, gears, chains and cams on a machine and containing a visible oil feed and oil supply.

Cabinets are 10¾ inches wide, 13¼ inches high, and 7¼ inches high. One piece top and side panel can be removed for access to various components of system.



Optional equipment includes: liquid level control to actuate an alarm or stop the machine when oil supply needs replenishing, electric heater for one-quart capacity models to maintain predetermined lubricant temperature and viscosity.

Micro-Fog lubricator is manufactured by the C. A. Norgren Co., of Englewood, Colorado.

(*Continued from p. 282*)

L. H. Butler (Univ. Wales, Cardiff), "Lubrication—A Study of its Action in Continuous Metal Deformation. Part II," *Steel Processing & Conversion,* **v. 43, no. 6, 1957, 326-33.**

The welding theory of friction assumes sliding starts only after accomplishment of equilibrium through deformation and work hardening of surface asperities. Three cases with different amounts of lubrication are considered in connection with deformation to allow bulk plastic deformation:

1. No lubricant or very thin film: after plastic deformation and rupture of oxide and/or oil film, sharp asperities penetrate and the surface damage done is due to ploughing of the tool. Smoothest possible tools are required to minimize ploughing and preserve the protective film.
2. Discontinuous confined film: tool and work piece squeeze out the lubricant until the highest asperities touch, trapping oil and forming a cushion against close contact so deformation and welding are slight, but surface finish is not especially bright.
3. Continuous lubricant film: no metal to metal contacts, deformation is entirely through the oil film with no surface ploughing. The establishing and maintenance of lubricant film in forging, wire drawing, wire rolling and extrusion is discussed.

The welding theory of friction must be modified when considering continuous metal flow. For power economy thick-film lubrication is desirable; but for fine finish, very smooth tools with thin-film lubrication is indicated. Boundary additives may reduce friction appreciably.

In rolling processes at either fast or slow speeds, low viscosity oil permits ploughing and shearing and resultant poor finish. The finish of the rolls has a direct effect on surface finish of the strip.

A discussion is given of the limiting of lubrication imposed by high temperatures, and a summary of deficiences in research in fabricating techniques. (*Abstractor: N. C. Morrell.*)

L. H. Butler (Univ. Wales, Cardiff), "Lubrication—A Study of its Action in Continuous Metal Deformation. Part III," *Steel Processing & Conversion,* **v. 43, no. 7, 1957, 387-95.**

In rolling aluminum, little data are available on the coefficient of friction, more work having been done on copper and steel. Values for coefficient of friction given by different investigators vary from 0.1 to 0.4 for using dry rolls and depending on the surface finish of the rolls. Data listed and references confirm that the coefficient to be representative, must be measured while bulk deformation of the metal is actually taking place. Addition of boundary lubricants reduces friction. It is believed that higher viscosity of the lubricant gives a lower coefficient of friction, but that film thickness and viscosity contribute to matte or dull finish. Formulas are developed and examples cited to show that variation in the coefficient of friction of rolls to strip in cold-rolling varies loads, torques, and reductions per pass. Staining of aluminum strip during rolling and its removal by anneal at 450°C, together with use of low-viscosity oils and boundary additives, is discussed. Desire to improve poor surface finish of rolled strip resulting from roll pick-up by welding to the roll surface during hot-rolling, leads to the development of emulsions to control roll pick-up. Metallic and ammoniacal soaps as emulsifiers; the addition of wetting agents; and the influence of film thickness are discussed, leading to these tentative conclusions: (1) Highly stable emulsions, by not depositing an oil film, may permit severe pick-up. (2) Unstable mechanical emulsions of free oil will deposit an oil film which, if adhesive, will give good lubrication. (3) Some emulsions may be broken by the volatilization of soap or the destruction of soap emulsifiers by the impurities in the water. Both (2) and (3) may result in difficulty in circulation. (*Abstractor: N. C. Morrell.*)

W. H. Stocker, "Honing 10,000 Sq. In. to 32 Mu-In," *American Machinist,* **v. 102, no. 1, 1958, 102-3.**

A description is presented of method and equipment used in large area honing. Information is provided on recommended coolants, speeds of rotation, and cycles per minute of reciprocation for cast iron, hard steel, soft steel, aluminum, brass, and bronze. (*Abstractor: D. F. Miller.*)

Anon, "Cutting Fluid Selection—The Metal Makes the Difference," *Metal Progress,* **v. 73, no. 2, 1958, 102-3.**

Results of a statistical survey of cutting oil users conducted by the ASM Advisory Group on Industrial Practices for factors affecting fluid selection are discussed. These factors include the metal to be machined, cost, quantity of production, tool material and the engineering services provided by the suppliers of the cutting oils. (*Abstractor: R. McKay.*)

B. W. Siemon (Standard Industrial Compounds Co.) "Selection of a Lubricant for Cold Drawing. Part I," W. B. Bauzenberger (Apex Alkali Products Co.), "Part II," *Iron and Steel,* **v. 33, no. 11, 1956, 105-8.**

The factors influencing the selection of a lubricant are speed and severity of draw, material drawn, and finish required. The primary function of the lubricant in wire drawing is the reduction of heat. Wire-drawing lubricants are recommended in accordance with the type of wire, the number of reductions, and the finish. Classes are straight soap, soap-fat combinations, petroleum oil, and water-emulsifiable oils. Examples of each type and the characteristics and performance of each are given. (*Abstractor: D. F. Miller.*)

Anon., "Lubrication of Highway Construction Equipment," *Lubrication* **(The Texas Co.), v. 43, no. 7, 1957, 77-92.**

Bigger and faster road building equipment operating under adverse service conditions demands special consideration. Operating in dirt, mud, water and extremes of weather conditions is the rule rather than the exception. A plan recommending the lubricants and lubrication intervals for the engines, air compressors, electrical motors and other parts of the equipment is shown. Problems involved in the lubrication of the various items are discussed. Also, the necessity for setting up good storage and handling facilities and a well-planned preventive maintenance practice which can be properly executed is discussed. Cleaning the equipment for relubrication will uncover fittings caked with mud and assure clean lubricant being applied. Keeping accurate records of the servicing done on each piece of equipment may serve as a warning of possible trouble. For example, excessive oil consumption is evidence of poor lube fittings or oil leaks—items which can be checked at once by the mechanic. Also, these records will indicate when the machine is nearing the over-all stage. (*Abstractor: F. Hardy.*)

E. N. Archibald (United States Steel Corp., Pittsburgh, Calif.), "Modern Technique in the Cold Reduction Sheet and Tin Plate," *Iron and Steel Engineer,* **v. 34, no. 5, 1957, 141-6.**

Techniques used in operation of five-stand tandem, four-high cold reduction mill are discussed with illustrations of adjustment methods and description of equipment. The rolling solution used is a mixture of 10 percent oil in water which is applied to both edges and center of strip. The solution serves as a roll coolant and a rolling lubricant to reduce power required. Under high pressure, the difference in speed of roll and strip requires reduction in surface friction by lubrication. Insufficient lubrication causes tearing of strip surface, excess lubrication results in slipping. Quantity of lubricant also influences roll shape by controlling roll temperature. Normal practices are to reduce at least one-half to a maximum of one-tenth of original thickness. (*Abstractor: D. F. Miller.*)

PERSONALS

A. V. Causey has been promoted to general office manager of STRATOFLEX, INC., manufacturer of hose assemblies. His headquarters will be in Fort Worth, Texas.

James M. Gavin, former Chief of Research and Development, Deputy Chief of Staff, Dept. of the Army, has joined ARTHUR D. LITTLE, INC., Cambridge, Mass. industrial research consultants, as director and vice president.

The National Society of Professional Engineers has awarded the 1958 NSPE AWARD to Nathan W. Dougherty, dean emeritus of engineering at the University of Tennessee. Presentation was made at the society's annual meeting June 11-14 in St. Louis.

Arthur O. Willey, past ASLE Director, has been promoted to executive vice president of the LUBRIZOL CORPORATION, Cleveland, Ohio. Also promoted were: F. A. Nason, to vice chairman, board of directors; M. R. Clapp, from asst. manager, manufacturing division to vice president manufacturing; and R. J. Ozmun, administrative assistant to the president, has been elected to the board of directors.

GAVIN

WIZEMAN

WILLEY

NASON

GARLOCK PACKING CO., Palmyra, N. Y., has appointed Karl C. Wizeman Product Manager for their metal packings, and T. L. Denney, general sales manager.

Donald C. Deyle has been named Advertising Manager of the PFAUDLER CO., division of PFAUDLER PERMUTIT INC. with offices at Rochester, N. Y.

DENNEY

DEYLE

CLAPP

OZMUM

William Luthi has joined THE ELCO LUBRICANT CORP. as technical sales representative. He formerly worked for the Standard Oil (Ohio) Co. in product development and application, and previously had been service representative for the Diesel Div. of GM.

R. L. Gilmore has been elected president of the Steel Founders Society of America for the term 1958-59. He is president of the SUPERIOR STEEL & MALLEABLE CASTINGS CO., Benton Harbor, Mich. Also elected at the fifty-sixth annual meeting of the society were B. P. Hammond, (BLAW-KNOX CO., Pittsburgh), Vice President, and R. G. Parks (NATIONAL MALLEABLE AND STEEL CASTINGS CO., Cleveland), Treasurer.

In Memoriam

CLARENCE (Clary) E. PRATT

The Connecticut Section has announced with regret the death of Mr. C. E. Pratt, Chief Engineer of the Plume & Atwood Co., Thomaston, Conn. on April 21.

Mr. Pratt had been treasurer of the Connecticut Section, ASLE for the past two years and was active as chairman of the finance and scholarship committees. He had been employed at Plume & Atwood for 39 years and was associated with the Chase Brass Co. of Waterbury previously.

YOUR LUBRICATION PROBLEM IS OUR BUSINESS

Call in one of our specialists!

Contact the nearest member or representative of the Far-Best Group when you need:

Cutting Oils
Tapping Compounds
Drawing Compounds
Rolling Oils
Metal Cleaners
Sulfonated Oils
Heat Treating Compounds
Grinding Coolants
Rust Preventatives
Lubricant Greases
Lubricant Additives
Motor Oils
Specialized Lubricants
Lanolin
Industrial Soaps
Laundry Products
Sulfurized Oils

The Far-Best Corporate Group includes:

- **Allube Corp., 928 Allen Avenue Glendale, Calif. Chapman 5-1158**
  —33 years manufacturing experience
- **Far-Best Corp., 6715 McKinley Ave., Los Angeles, Calif. Pleasant 8-3181 and 2800 Commerce St., Franklin Pk., Ill.**
  —26 years manufacturing experience
- **O. L. King & Co., 782 Minnesota Street, San Francisco, Calif. Valencia 6-6701**
  —26 years manufacturing experience
- **Dacus Oil Corp., 782 Minnesota St., San Francisco, Calif. Valencia 4-5185**
  —25 years manufacturing experience
- **Sanford Process Corp., 6920 S. Central Ave., Los Angeles, Calif. Ludlow 3-4856**
  —10 years development and production experience

A total of 120 years' industrial experience in solving production and maintenance problems.

REPRESENTATIVES

Peacock Supply Co., Salt Lake City, Utah

Pacific Machinery & Tool Steel, Portland, Oregon

Carl F. Miller Co., Seattle, Washington

Far-Best, Inc., Aiken, South Carolina

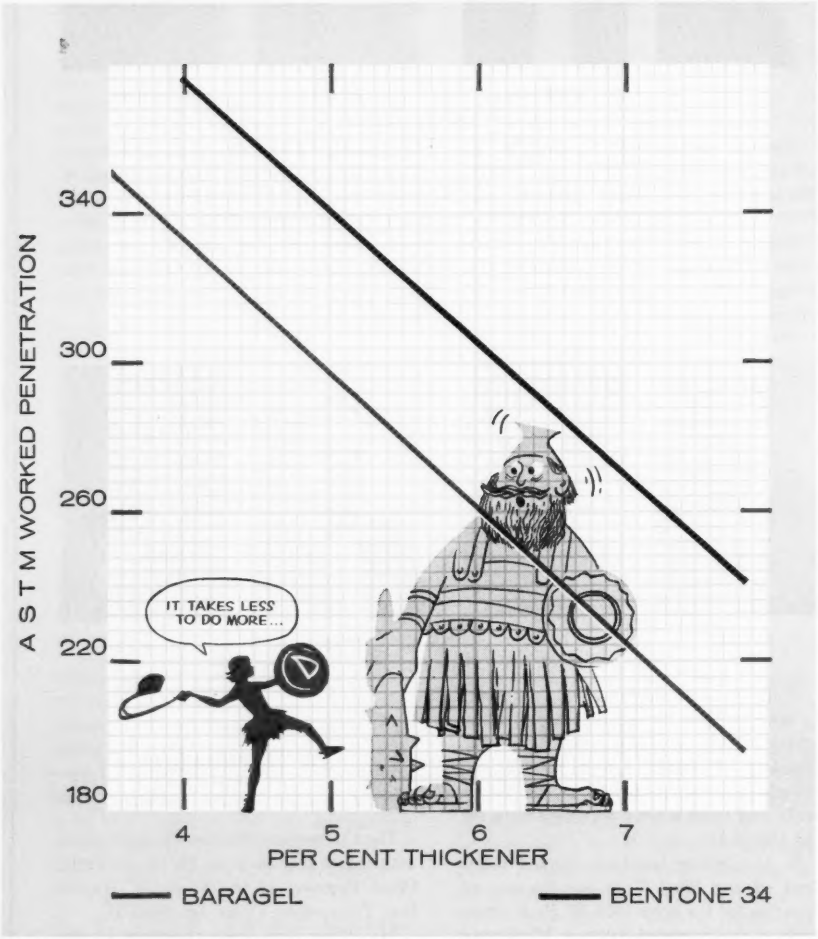
One of the 3 essentials for grease manufacturers is EFFICIENCY . . .

Number 3 of a series

BARAGEL* provides EFFICIENCY

BARAGEL provides EFFICIENCY because it gives more grease per pound of thickener.

BARAGEL is considerably more EFFICIENT than Bentone 34. In many oils, 15% to 20% *less* BARAGEL is required to prepare a grease of a given consistency.



BAROID

BAROID CHEMICALS, INC.

A SUBSIDIARY OF NATIONAL LEAD COMPANY

1809 SOUTH COAST LIFE BLDG. HOUSTON 2, TEXAS

*Trademark of National Lead Co.

Lube Lines

by A. F. Brewer*

TOLERANCE

Tolerance can have a number of meanings according to the intent of the user. At home, it may apply to how one regards the whims of the teen-age members of the family; or it may apply to some neighbor's habit of throwing noisy parties in his patio. The mechanical engineer, however, is more serious in his interpretation. He relates tolerance to a factor of safety in the design of mechanisms. Likewise the lubrication engineer, who applies tolerance to clearance in bearing design. In effect, tolerance in mechanics has to do with allowable leeway in size between mechanisms which must function in relatively close contact. As metals are affected by changes, in temperature any such change must be considered during the design stage when the machine is on the drawing board. With the exception of the softer bearing materials, which can be scraped to increase the clearance, it is not too practicable to change this characteristic materially in machine parts without possibly having some effect on alignment. In other words, it is a highly precise factor which must never be disregarded in machine design, assembly, and lubrication.

Tolerance or clearance can vary according to the intricacy of the mechanism; also according to the means by which lubrication is maintained. In connection with plain or sleeve type bearings one of the common definitions of clearance is the difference between the diameters of the shaft and the bearing. The designing engineer has established a factor known as the C/D ratio, where C is the clearance and D the diameter of the shaft. This can be varied according to the surface finish of the respective contact parts and the coefficient of friction. Normally the latter increases as the C/D ratio is decreased. Here the lubrication engineer must be concerned because the fluidity or pumpability of the lubricant enters into the picture. Good surface finish plus controlled lubrication will promote less friction and enable use of more fluid lubricants and lower clearances. In other words the lubricating film will function more actively as a friction-reducing agent and less actively as a coolant for heat removal.

With the realization that there are other conditions such as shaft speed and load which also exert a controlling effect, modern machinery such as an automotive engine, for example, can be designed for fantastically low clearances according to the bearing metals used. In terms of clearance per inch of shaft diameter the following data are significant:

Copper-lead Aluminum	..... 0.0010 inch
Cadmium-silver Copper	..... 0.0008 inch
Babbitt metals Tin base Lead base	..... 0.0005 inch

It is interesting to note that those metal compositions such as the Babbitts (particularly lead) which can have some inherent self-lubricating qualities themselves, permit the use of lower clearances per inch of shaft diameter. In service, however, clearance can be changing by an infinitesimal amount at each turn of the shaft. This must be realized and duly considered when the machine is down for overhaul.

Management should be concerned with clearance or tolerance because of the possible relation to oil consumption. Research has indicated that too much clearance can contribute to unnecessarily high oil consumption. Conversely, too little clearance, i.e., too tight a bearing fit, can lead to starved lubrication. In other words the clearance must be decided upon with respect to what the oil must do. In a full-pressure system oil-flow control is more practicable than in a mechanism in which oil splash from bearings must serve to lubricate other moving parts. Where there may be a chance of leakage it is apparent that excessive oil flow escaping at the bearing ends could lead to loss.

Tolerance, of course, also, can be extended in its more liberal meaning to the question of lubrication recommendations. It is quite true that practically any oil or grease will provide lubrication of a sort. Too often this can be the "out" for the price buyer. At the same time it is true that oftentimes quite a number of lubricants can do a passable job on a specific type of mechanical assembly. Tolerance comes into the picture when management considers the fact that so often with modern precision machinery there is a specific type of lubricant which is *best suited* for a specific set of operating and design conditions. This is all the more important in view of the complexity of modern machine design and the extent to which lubricating value is improved and made more durable by modern additives. Both are costly, but both can be a boon to management when they are regarded with due consideration of their productive value: the machine in terms of dollar value of output, the lubricant in terms of its protective and insurance capabilities.

Just as design must be a criterion in deciding upon the degree of refinement and the chemical make-up of a lubricant, so must an impartial attitude of tolerance prevail between the designer, the lubrication engineer, and management. They all have specific problems, but a common objective as far as machinery operation is concerned: *PRODUCTION*.

* Consultant, and author of *Basic Lubrication Practice*.

BOOK REVIEW

P. S. Barna, "Fluid Mechanics for Engineers," Butterworths Scientific Publications, London, 1957, x + 377 pp., $11.50. Reviewed by T. C. Tsu, Westinghouse Research Laboratories, Pittsburgh 35, Pa.

The text, consisting of three parts, is intended for undergraduates in mechanical or civil engineering. Part I contains 9 chapters and 234 pages on such topics as fluid statics, perfect and viscous fluids in motion, flow in closed conduits and open channels, fluid metering, dimensional analysis, boundary layer theory and elements of wing theory. There is only one chapter (41 pages) in Part II, dealing primarily with one-dimensional compressible flow. Part III is devoted to rotodynamic machinery, more commonly known as turbo-machinery in this country. It has 3 chapters and 91 pages. There are a list of references, worked-out examples, and problems in each chapter.

The book is profusely illustrated. Only simple mathematics is used with nothing more advanced than elementary calculus. Although the author states in the preface that "emphasis is laid upon the broad representation of the fundamentals," the reviewer fears that this goal has not been reached. Many important concepts are explained loosely, or not at all. For example, streamlines are defined as "tangents to the fluid velocity at every point along their length." The relation between streamlines and pathlines is not explained. Streak lines are not even mentioned. No distinction is made between steady motion and unsteady motion. On boundary layer separation and flow over curved surfaces, the author merely recites certain physical phenomena without explaining why.

In the chapter on wing theory, the term "chord line" is used before the terms "leading edge" and "trailing edge" are introduced. On discussing the energy equation in Chapter 10, the conservation of energy is written as $dQ = dE + p\,dv/J$ without pointing out its restrictions, although this is a common fault of many elementary textbooks. The energy equation (10.2) includes only terms representing heat transfer, changes of enthalpy, kinetic energy, and elevation. The work term is added as an after-thought in equation (10.3) with the statement that "mechanical work W is also considered as a form of heat." The chapter includes discussions on one-dimensional isentropic flow and Fanno-line flow, but nothing is said about Rayleigh-line flow. Partly as a consequence of this, the discussion on normal shock is sketchy at spots.

In section 11.10, "Impeller Design Based on First Principles," the discussion is really more empirical than fundamental. The same is true of section 12.4, "Blade Design Based on Constant Element Effeciency." Would it not be better to omit these sections in a book of this nature? Cavitation is discussed in Part III, but such other equally important phenomena as surging, rotating stall, and secondary flow are ignored. The author appears to have restricted his discussions to hydraulics in certain portions of the book, and broadened his scope to fluid mechanics in others. Thus, in discussing drag of fully or partially submerged bodies, the effect of Reynolds number, Froude number, and relative roughness is mentioned but the effect of Mach number is not. The last three chapters seem to be dealing mainly with hydraulic machinery although the more general heading "Rotodynamic Machinery" is used.

In Chapter 12, axial-flow machinery is explained by means of an isolated airfoil theory on the ground that more accurate theories are rather complex. One wonders whether it is better to oversimplify the physical phenomena and mislead the student, or to go into some extra length and give the student a more precise picture? Throughout the book, one often encounters sentences beginning with "Experiments show . . ." or "It is observed experimentally . . ." One cannot help apprehending that this might tend to encourage the student to rely indiscriminately upon experiments, rather than to develop his power of reasoning.

The book contains a number of misleading and confusing statements. Examples are: "For incompressible fluids $dE = 0$ . . . hence enthalpy change $= v\,dp/J$" (p. 281). "On leaving the impeller the fluid loses momentum with increasing radius in accordance with the principle of conservation of momentum." (p. 298). Here the author fails to distinguish between linear momentum and angular momentum. In axial-flow locity . . . must follow the law of the free vortex" (p. 335); and "values of the pitch/chord ratio should be equal to or greater than one." (p. 338). In discussing turbulent flow, the logarithmic law of velocity distribution is mentioned on p. 41 but the 1/7 power law is not mentioned until much later on p. 174. The coordinates of figure 8.9 are mislabeled and quite confusing. Figure 8.10 serves no useful purpose.

There are numerous errors and misprints. To save space, only a few of them will be cited. In the equation for L^* on p. 164, the coefficient should be 0.065 instead

(*Continued on p. 320*)

—Section News—

BOSTON—Ladies night at the Museum of Science highlighted the May meeting with demonstrations by the museum staff of the satellite and rocket exhibits and the talking transparent woman. Dinner followed the social hour and tour. . . . CHICAGO—C. P. Monti (*The Texas Co.*) spoke on Hydraulic Oils at the May meeting. By analysis of the various cost factors in the selection of a hydraulic oil it is easy to demonstrate a significant savings to maintenance costs by selection of a premium grade hydraulic oil. June 12 was the annual golf party ending the 1957-58 year. Dinner and door prizes followed. . . . DULUTH-IRON RANGE—Mr. Davis of the *Standard Oil (Indiana) Co.* spoke on "Additives in Oil." . . . KINGSPORT—Elected to office for 1958-59 were: H. E. Goddard (*Blue Ridge Glass Corp.*) Chairman, L. Rivinette (*Tennessee Eastman Co.*) Vice Chmn., P. J. Galbreath (*Tennessee Eastman Co.*) Sec.-Treas., and H. Harr (*Tennessee Eastman Co.*), H. E. Coggin (*Georgia-Carolina Oil Co.*), and D. T. Martin (*Union Carbide Nuclear Co.*) as directors. . . . LOS ANGELES—W. H. Mandy (*The Texas Co.*) spoke on "Solving Lubrication Problems in Heavy Mill Equipment" before the May meeting of the Section. . . . MONTREAL—New officers announced include: J. W. Ussher (*British American Oil Co.*) Chairman, G. Beauchamp (*Montreal Transportation Commission*) Vice Chmn., J. H. Woodward (*Woodward, Lemieux & Saunders Ltd.*) Secretary, and P. T. Erickson (*Northern Electric Co. Ltd.*) Treasurer. . . . NORTHERN CALIFORNIA—G. H. Hommer (*Tidewater Oil Co.*) has been elected Chairman, H. M. Trowbridge (*Shell Oil Co.*) Vice Chairman, J. L. Dreher (*California Research Corp.*) Secretary, and J. LeSire (*O. L. King & Co.*) Treasurer for the coming year. E. C. Ike (*Western Die Casting Co.*) will be the new Program Chairman and H. V. Scheffel, Jr., Membership Chairman. . . . PITTSBURGH—Mr. V. Ratnan and Mr. G. Somyaji, Indian engineers studying steel production under the Indian Steel Training & Education Program were guests at the March meeting. W. J. Varetoni (*Cities Service Oil Co.*) spoke on "Quenching Oils." In April, the Section toured the Gulf Oil Company's Engine Laboratories at Harmarville, Pa. June was the annual social meeting which featured dinner and dancing. . . . SYRACUSE—May meeting of the Section heard a talk on "Petroleum Base Rust Preventives" by H. B. Carpenter (*Esso Standard Oil Co.*) . . . TWIN CITIES—A. J. Stock (*Acheson Colloids Co.*) presented information on "The Lubricating Properties of Polytetrafluorethylene 'Teflon' Films."

ASLE News Notebook

Executive Reports

Summary reports of those presented before the board of directors of the Society, April 22-24, 1958 at Cleveland, Ohio.

Treasurer

Report of the auditor (see June, *Lubrication Engineering*), covering the period ending December 31, 1957 was presented. Report was accepted (58-17).

Eastern Region

Ten of the eleven Sections in the eastern region have shown aggressive growth and activity. Membership growth is demonstrated by those Sections that promote education courses. New Sections have been reported for Rochester, N. Y., Richmond, Va., and the Huntington-Charleston, W. Va. areas. Future Sections in Erie, Pa. and East-Central Pennsylvania appear possible.

Central Region

Membership increased by 59 during the year. One Section has held an education course and two additional Sections plan courses for the near future. Academic participation in the Society's activities is lacking in the Central region. Akron-Canton, Ohio, Atlanta-Birmingham, Ga., and Toledo, Ohio areas are potential future Sections.

Midwestern Region

Growth of membership in the midwestern region during the past year totals 53. Some Sections have shown net losses for the period. A new Section in Dallas-Ft. Worth, Texas has been reported during the year. A prospective Section in the Quad Cities areas appears certain. A new Section for New Orleans, La., seems possible. Education courses have been held by two of the Sections and two additional Sections will sponsor courses this fall.

Executive Secretary

A report on the advertising for the journal was presented which showed a 11 percent decrease in advertising committments for 1958. This is in spite of new accounts secured by our west coast representatives. Prospects for additional space contracts for 1959 based on prospective advertisers within the central region, currently being contacted by our central region sales representatives, appear favorable. Much further information about our subscribers and members will be required in the form of a pilot study to determine to what extent classification and circulation records must be maintained to support advertising activities.

Canadian Region

An education course for the Montreal Section is planned for the future. A plan of inviting top management to attend one meeting of the Montreal Section was favorably received: 21 firms were represented at the Section's April meeting. Meetings have alternated between Toronto and Hamilton, Ontario in recent months. It appears desirable to form two Sections in Ontario to obtain the support of industry, now seriously limiting membership growth in the two areas. Section officers are working to this end.

Western Region

Each of the four Sections in the western region have shown active progress in Section activities and growth. A prospective Section in San Diego, Calif., area lags as a result of insufficient experienced leadership. Based on past activities of the Los Angles Section, a suggested organization and activities guide was presented. Its use by other Sections, as necessary or desired, was recommended (see your regional vice president for this information.)

Committee Reports

Tellers

Based upon returns counted on March 24, 1958, the following were elected directors of the Society:

E. E. Bisson (National Advisory Committee for Aeronautics)
R. J. Torrens (Eastman Kodak Company)
B. G. Symon, industrial director (Shell Oil Co.)

report of the committee was accepted (58-19).

Nominations

A slate of nominees was presented to the board. In the election which followed these men were elected to office for the 1958-59 term:

A. B. Wilder—Vice president at large
J. L. Finkelmann—Secretary
J. W. Peterson—Treasurer
D. F. Wilcock—Eastern regional vice president
P. A. Asseff—Central regional vice president
H. W. McCulloch, Jr.—Midwestern regional vice president
R. C. Dishington—Western regional vice president
S. C. M. Ambler—Canadian regional vice president

As representatives for the Joint Technical Committee's executive committee, the board elected T. W. Havley and R. W. Blair. Motions covering the previous actions include 58-20 through 58-24.

By-Laws

An annual report of the activities of the committee was not available at the time the director-sponsor reported to the board.

(*Continued on p. 317*)

Tolerances .0002 with Cities Service Cutting Oil!

If you think the days of the precise craftsman are a thing of the past, you ought to take a tour through Arch Gear Works at North Quincy, Massachusetts.

There, you'd see some of the nation's foremost specialists in precision gearing going about their jobs with the most painstaking accuracy.

Such accuracy is absolutely vital at Arch Gear Works, because this unusual firm produces amazingly intricate mechanisms involving as many as 50 tiny precision gears... gears that automatically control the speed and torque of sensitive electro-mechanical devices.

In this highly complex, precise operation, Cities Service is the choice of cutting oils for a very simple reason: Cities Service Cutting Oils deliver .0002 tolerances and the finest possible finish. Few oils can match this performance.

With equally outstanding results, Arch Gear Works uses Cities Service Anti-Corrode to protect its gears during shipment, and Cities Service Pacemaker Oils for general lubrication and hydraulic machinery.

But you needn't operate a gear works to prove that Cities Service lubricants are geared to *your* operation. Simply talk with a Cities Service Lubrication Engineer. Or write: Cities Service Oil Company, Sixty Wall Tower, New York 5, N.Y.

Specialist Assembles Tiny Gear. Some mechanisms contain as many as 50 tiny precision gears—all produced with the aid of Cities Service Cutting Oils—and protected during shipment by Cities Service Anti-Corrode.

CITIES SERVICE

QUALITY PETROLEUM PRODUCTS

LUBRICATION ENGINEERING

DESIGN RESEARCH APPLICATION EDUCATION MAINTENANCE

Journal of the American Society of Lubrication Engineers *Vol. 14 No. 7 July 1958*

FUNCTIONAL DIVISIONS OF ASLE

In a Society as young as ASLE it is frequently necessary to re-define some of the activities, responsibilities, and relationships of one group to another as we grow. Such is the case with our major technical groups—the Joint Technical Committees (JTC) and the Joint Industry Councils (JIC).

Among the questions most frequently asked are: "What is the distinction between the technical committees and industry councils?" Or, "Why do we have both industry groups and technical groups?" The answer is readily apparent once you recognize the problems faced by a technical society.

The Joint Technical Committee, through the various individual technical committees, are responsible for the engineering and scientific functions of the Society *in specific fields of technical interest.* Their scope of jurisdiction is vertical within the specific field; their approach to lubrication as a science is basic—the problems associated with specific research and design.

By contrast, the Industry Councils are oriented horizontally, covering a wide variety of technical fields for which there are applications within an entire industry. Their interests are primarily in the application of the science of lubrication engineering.

The Joint Technical Committees

In addition to the Technical Coordinator and vice chairman, eleven technical committee chairmen and an executive committee of four elected members comprise the JTC. Executive committee membership is obtained by nomination and election by the Board of Directors. This group is responsible for the technical policies, research, liaison, and assistance necessary to fulfill the objectives of the Society as determined and approved by the Board of Directors.

Through its member technical committees, the JTC acts as a clearing house for technical information. Through its liaison representatives it functions to keep the Society abreast with similar activities in allied organizations. Definitive documents and recommendations for sponsored research projects fall within the responsibilities of the JTC.

These two areas, liaison and research, are of major importance to the Society. Through the efficient operation of committees to define and augment these needs, ASLE will be able to assume its rightful place in determining the standards, methods, and tools which affect our segment of science.

Joint Industry Councils

Although only one year old, the horizontal organization of industry councils within the ASLE has become an accomplished fact. The JIC is administered by an Industry Coordinator appointed by the vice president at large.

Duties and responsibilities of the JIC have been defined as "agents of the Society in programs, projects and activities designated to improve industrial lubrication." These two groups represent the interests of industry, whether it be at the research and design levels, or the practical application of this basic research.

Membership in these groups is open to all qualified individuals. Through the active participation of the membership in the many diverse interests, ASLE can provide the leadership in scientific lubrication throughout the world.

Calvert L. Willey, *Executive Secretary*

Greases Stable to Radiation Under Dynamic Conditions

J. R. A. Handschy, J. W. Armstrong, and B. E. Gordon,
Research Laboratory, Shell Oil Company, Martinez, California

Conventional greases exhibit marked changes in physical properties upon exposure to large doses of high-energy radiation. Heretofore, these changes have been evaluated in the usual bench-scale tests after irradiating the greases in vials under static conditions. While this method is quite effective in identifying and eliminating those products most susceptible to radiation damage, it yields little information on the progressive degradation of greases under the combined effects of simultaneous irradiation, oxidation, and mechanical working typical of actual service. To overcome this limitation, a modification of the Shell Roll Tester suitable for underwater operation has been developed and installed in the Gamma Facility pool at the Materials Testing Reactor, Idaho Falls, Idaho. Details of this test rig are presented in the text. The equipment permits periodic examination of the degradation in mechanical stability of grease under dynamic irradiation conditions. Mechanical stability has been found to be the parameter most sensitive to radiation.

The screening of many greases and grease components under both static and dynamic conditions has indicated the thickeners and oils which show the greatest resistance to radiation degradation. Greases prepared with these components retain a good measure of their initial serviceability even after exposure to more than 5 x 10^8 roentgens.

INTRODUCTION

In common with all the rest of modern industry, the growing nuclear power industry will require lubrication. It is certain that many of the requirements of nuclear power plants will be satisfied by conventional lubricants. Carefully selected products are entirely suitable where only mild fluxes are encountered. However, a need is now arising for lubricants (including greases) of enhanced radiation stability. Such appears to be the case already in the AEC-Air Force program to develop a nuclear-propelled aircraft. This paper reports the progress made by the authors' company in efforts to formulate radiation-resistant greases.

The object of this program has been to develop products capable of lubricating conventional type (ball, roller) bearings of all sizes, since it is expected that designers will favor proved components for use in this unfamiliar environment. Few actual nonmilitary applications are known; the most severe yet reported is a pump subjected to a flux of 10^5 roentgens (r) per hour. Details of the military applications are classified and not known to the authors, but dose rates at least this high are expected.

To date, relatively few laboratories have reported studies on the radiation stability of greases (1-6).[1] Much of this published work seems to have been done in support of the nuclear-propelled aircraft program, and was not released for publication until about 1956. The early work at this laboratory paralleled some of that reported in the references cited. The results obtained at the authors' company corroborate many of the published findings.

In the course of this program, the following approach to the problem was developed. The primary function of any grease—even a radiation-resistant one—is obviously lubrication. Hence, the quality of any experimental formulation with respect to all normal specifications should be established before an evaluation of its radiation stability is undertaken. Satisfactory bearing performance at temperatures corresponding to service conditions is considered the most significant of these specifications. As one would expect, some properties must be sacrificed to gain radiation stability. In particular, it seems impossible at present to combine wide operating temperature range (e.g., beyond 450°F) with extreme radiation stability. As a compromise, this laboratory has established the requirement that a grease must provide as least 300 hours bearing performance at 300°F before it will be recommended for multipurpose radiation-exposed service. (It is hoped to increase this specification to 600 hours soon.) Greater radiation stability can be achieved in products not required to operate above 200°F.

The oxidative degradation rate of most familiar lubricants (silicone oils are an exception) increases so rapidly with temperature that above 500°F or so it considerably exceeds the radiolysis rate expected in even high-flux applications (10^5 — 10^6 r per hr). For

[1] Numbers in parentheses refer to references at the end of the paper.

service at such elevated temperatures, one attempts to maximize the thermal and chemical stability, and hopes that radiation will not shorten too drastically the already temperature-limited life of the grease.

A final obseravtion is that as many as possible of the major stresses encountered by the grease in service (radiation, oxidation, temperature, shearing, etc.) should be imposed simultaneously in the experimental evaluation of the product. This philosophy has led to the development of the first of a series of dynamic testers which is described later.

IRRADIATION FACILITIES

Several facilities have been employed in performing the irradiations of this study. Static irradiations have been conducted at Shell Development Company, Emeryville, California, Southwest Research Institute (SWRI), San Antonio, Texas, and the Materials Testing Reactor (MTR) Gamma Facility, Idaho Falls, Idaho. Dosimetry at each facility has been performed by members of the facility's staff, and their results have been accepted without change.

Most of the static irradiations reported herein have been done at the authors' company, using their 3-kilowatt, 3-Mev Van de Graaff generator. This machine produces a pencil-size, downward-directed beam of electrons which can be rapidly scanned across a line up to 12 inches in length. At full machine power the instantaneous dose rate delivered by the beam to unit density material exceeds 10^{11} r per hr. Cooling the sample therefore becomes a problem, particularly in the case of nonfluid materials. The solution worked out by members of the Van de Graaff staff is to spread the grease in a layer ⅛ inch thick at the bottom of a shallow 10 x 10 inch pan. The under side of the pan is water cooled. The scanning width is adjusted to 10 inches, and the pan is passed slowly (¼ inch per second) back and forth under the beam until the required dose has been delivered. The top of the pan is loosely covered with aluminum foil to minimize any fire hazard. As a consequence, all the air is probably driven out of the pan early in the irradiation by radiolytic hydrogen. The average temperature of the grease can easily be controlled by regulating the flow and temperature of the cooling water.

A few of the present irradiations have been done at SWRI, in their 8000-curie cobalt-60 source. The dose rate is about 2 x 10^6 r per hr. The greases are placed in uncapped 150 ml glass bottles, which are in turn placed in thin steel bombs whose screw closures are tightened lightly. Due to the operating schedule at SWRI, the samples are exposed intermittently, a few hours at a time, until the required dosage has been achieved.

At the MTR Gamma Facility, spent reactor fuel elements under about 20 feet of shielding water are used as the radiation source. The same 150 ml sample bottles are used. Five of them are placed in a cylindrical aluminum bomb, which is vented to the atmosphere above the water. The dose rate varies from 10^7 to 2 or 3 x 10^6 r per hr.

For dynamic testing, the conventional Shell Roll Test design (7) was modified for underwater operation at the MTR Gamma Facility. The major change made was to reduce the length of each unit to ¾ of that of the standard equipment. The cylinder wall thickness was reduced to improve the transmission of radiation. All other important dimensions were retained (Table 1).

TABLE 1. Roll Tester Dimensions

	STANDARD	MODIFIED
Cylinder, inside length, mm	180	138 (5.44″)
Cylinder, inside diameter, mm	90	90 (3.54″)
Cylinder, wall thickness, mm	12.5	2.3 (0.09″)
Roller length, mm	176	133 (5.25″)
Roller diameter, mm	60	60 (2.35″)
Roller weight, kg	5	3.7
Grease charge, g	75	60
Speed of rotation, rpm	160	175
Air volume in loaded cylinder, cc		425

The complete apparatus consists of a frame holding five such units one above the other (Figure 1,) to which is attached a 15-foot long aluminum pipe housing the drive shaft and supporting the motor above the water (Figure 2.) The rig is constructed entirely of stainless steel, except for the bronze bushings, lead gaskets used to seal the cylinders, and the aluminum pipe. The exterior of the rollers and the inside surfaces of the cylinders are protected with hard chrome plating 4 mils thick. The device occupies two of the 4-inch-square spaces in the Gamma Facility grid (Figure 3.) At intervals, it is withdrawn from the pool so that the consistency of the greases can be measured; also, during these periods the dosimetry is performed.

The grease consistency is determined with an ASTM penetrometer using the Shell cone regularly specified for the test. Owing to the small quantity of grease used, a special cup had to be designed (Figure 4.) In comparison runs on six different greases, the combination of this special cup and the modified roll tester gave results which agreed with those of the standard equipment, within the repeatability of the test, for tests up to 240 hours in duration.

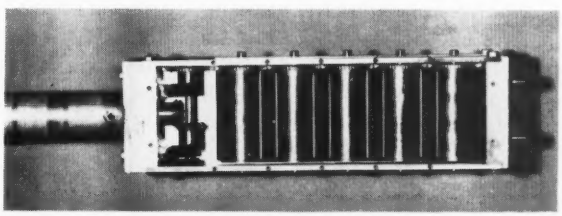


Figure 1. The lower part of the roll-test equipment, showing the five cylinders and the gear train which turns them. The two pins at the right fit the holes in the Gamma Facility grid (Figure 3.)

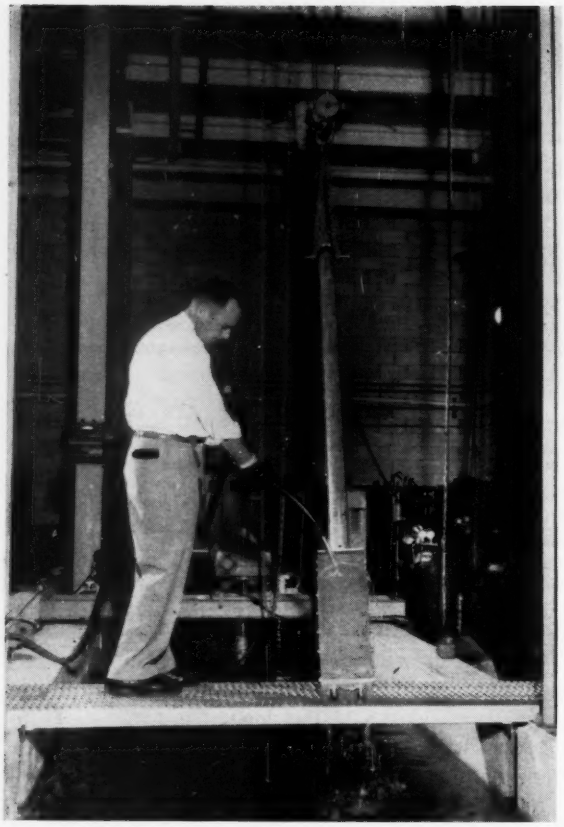


Figure 2. Removing the roll tester from the MTR Gamma Facility pool. The motor at the top of the 17-foot long rig is nearly hidden by the hoist block. The unit must be hosed and wiped after withdrawal to remove radioactive contaminants picked up from the water.

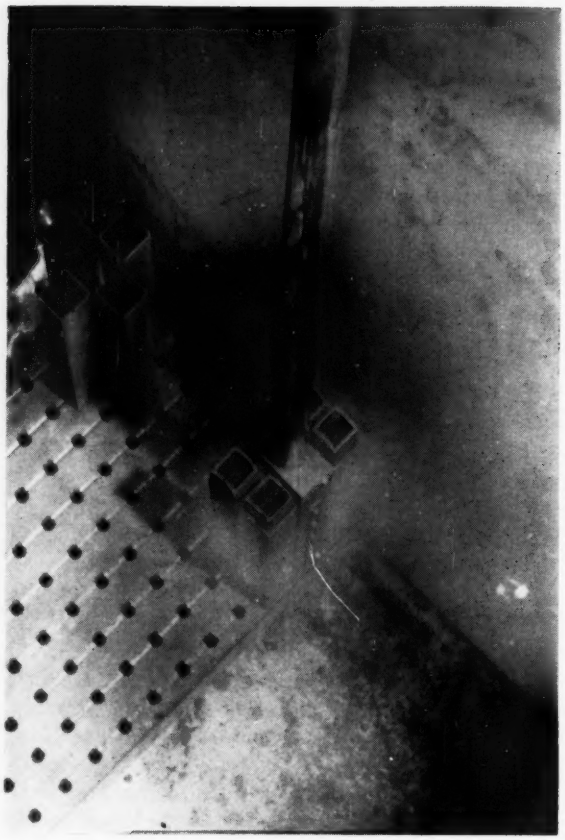


Figure 3. The roll tester in operating position (under water.) Two fuel elements face each side of the tester. The haze around the fuel elements results from the Cerenkov glow caused by the radiation.

The correlation between the performance of a grease in the (standard) roll test and its performance in actual service has been discussed elsewhere (7). Concerning the present test, it is felt that the absorption of a given dosage of radiation will cause the same relative degradation in the performance of a grease in actual service as is observed in the modified roll test.

EXPERIMENTAL IRRADIATIONS

The experiments reported herein are based on earlier work which, as indicated above, is similar to some of that reported in the references cited and hence will be only briefly reviewed. Usually, the initial effect of irradiation is to soften a grease. This occurs in the range of about 5×10^6 r to a few times 10^8 r. This softening is most pronounced in formulations containing ester-type oils, which become acidic upon irradiation, and in greases gelled with conventional metallic soap thickners. (Figure 5 illustrates the softening of a conventional lithium hydroxy-stearate grease under dynamic irradiation.) The intial softening is followed by a period of hardening, which typically occurs at dosages above 5×10^8 r. At a sufficiently high dosage (up to 10^{10} r) almost any organic lubricant will solidify.

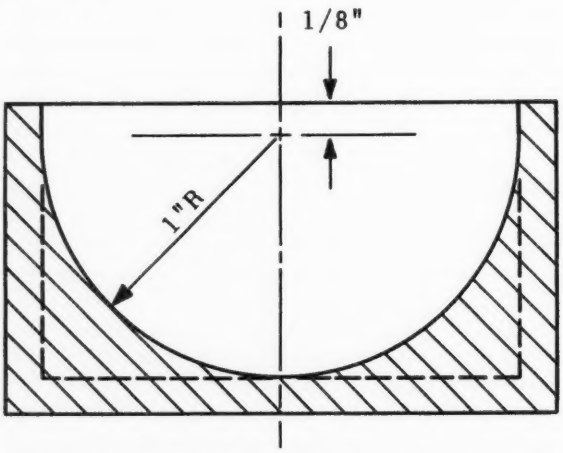


Figure 4. Sectional view of the special penetrometer cup used with the roll tester. The design of the standard cup is indidated by the dashed lines.

Polymeric oils, notably silicones, thicken quite rapidly upon irradiation. Consequently silicone greases may solidify at dosages below 10^8 r, with no initial softening observed. Hydrocarbons are one of the most stable classes of compounds. Aromatics are as much as ten

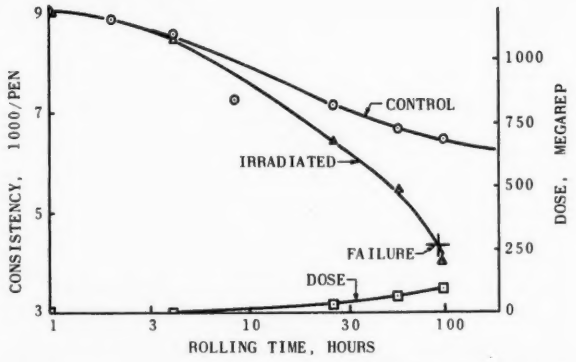


Figure 5. Conventional grease. Irradiated and unirradiated (control) roll tests of a conventional soap-thickened grease. The test life of the grease is measured to the time at which it reaches a penetration value of 230 (consistency of 4.35.) The accumulation of radiation dosage incident upon the roll-tester is indicated by the third curve and the scale at the right side of the figure. Due to the shielding effect of the metal parts, the dosage actually absorbed by the grease is probably about half of the value shown. (A megarep equals 10^6 r.)

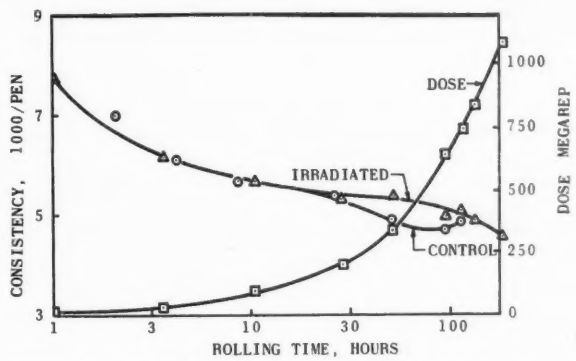


Figure 6. Aromatic Oil—Clay Thickener. Irradiated and unirradiated roll tests of a clay-thickened alkylated-aromatic grease. Note that the dose rate in this and subsequent tests was much higher than in the test of the conventional grease (Figure 5.)

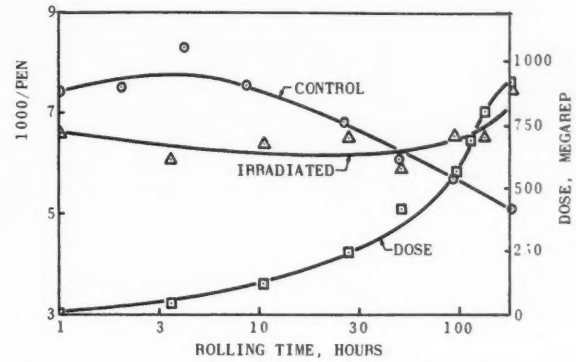


Figure 7. Aromatic Oil—Siliceous Thickener. Irradiated and control roll tests of a hydrophobic-silica-thickened alkylated-aromatic grease.

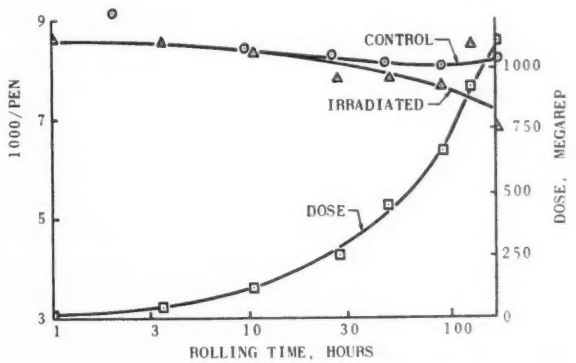


Figure 8. Aromatic Oil—Dye thickener. Control and irradiated roll tests of an indanthrene-dye-thickened alkylated-aromatic grease. The curves shown in Figures 6-8 indicate that the gelling power of these thickeners has not been appreciably affected by radiation.

times more stable than aliphatics. These results suggest that the most stable grease would be a combination of an aromatic hydrocarbon oil and a nonsoap thickner.

An initial step in the development of a radiation-resistant grease was to screen a number of nonsoap thickners. To do this it was necessary to select for the oil phase a fluid of high radiation stability, to serve as a medium in which to test the thickners. Static irradiations of a variety of oils showed a synthetic alkylated naphthalene to meet this requirement. A series of greases was prepared by thickening this oil with representative nonsoap thickners. After static and dynamic tests it developed that three of these, indanthrene*, hydrophobic silica, and a clay, exhibited little change in consistency upon exposure to as much as 5×10^8 r. Dynamic irradiations of these three are shown in Figures 6-8. The dye thickner had previously been found capable of superior high temperature performance (8).

While showing excellent radiation stability, these alkylated-naphthalene greases were limited by the volatility of the oil to applications where the temperature did not exceed 200°F. A number of oils were examined in an effort to circumvent this limitation. Silicone and diester types possess desirable high temperature properties, but had already been rejected due to their radiation susceptibility. Synthetic aromatics were of particular interest on account of the known radiation stability of aromatics, but all (commercial) products examined were found to be too volatile. Several mineral oil fractions were then examined. The most promising were suitably treated residues having fairly high aromatic content.

Experimental greases were then compounded from the selected thickners, selected mineral oil and inhibitors. These were then rigorously screened under both static and dynamic conditions. Some of the data obtained with these greases are presented in Table 2.

As the data indicate, these greases give bearing performance approaching that required in Military Specification MIL-L-3545, "Lubricating Grease; High Temperature", which requires a minimum of 600 hours performance at 300°F.

* N,N'-dihydro-1,2:2',1'-anthroquinoneazine or 6,15-dihydro-5,9, 14,18 anthrazinetetrone. This material is marketed as dyestuff.

TABLE 2. Properties of Nonsoap Mineral Oil Greases

Grease	A	B	C	D
THICKENER	INDANTHRENE	HYDROPHOBIC SILICA	CLAY	INDANTHRENE
Penetration, ASTM				
Unworked	287	263	268	336
Worked 60 strokes	291	274	276	342
Bomb Oxidation, pressure drop				
after 100 hours, psi	7	10	14	8
after 200 hours, psi	14	17	23	19
Bearing Performance, Annapolis				
Rig, 10,000 rpm, 300°F,				
hours to fail	452	794	898	386
	436	376	562	356
Average	444	585	730	371

After static exposure to 1 x 10^9 r on the 3Mev Van de Graaff generator, these greases exhibited the properties shown in Table 3.

TABLE 3. Properties of Nonsoap Mineral Oil Greases After Irradiation

Grease	A	B	C	D
Increase in unworked penetration	49	−37	−32	14
Increase in worked penetration	46	34	9	11
Bomb Oxidation, pressure drop				
after 100 hours, psi	16	24	14	24
200 hours, psi	27	46	23	43
Bearing Performance, Annapolis				
Rig, 10,000 rpm, 300°F, hours				
to fail	100	132	40	148
			36	142

Greases A, B, and D retained a good measure of their consistency and bearing performance potential. Grease C, while showing little change in consistency, failed the bearing test. It is interesting to note that the oxidation inhibitors selected were completely destroyed by this exposure. To illustrate this, oxygen absorption rates of Grease D with and without inhibitors before and after irradiation are presented in Figure 9. The oxygen absorption rate of the inhibited grease after exposure corresponds quite closely with its uninhibited, unirradiated counterpart.

Mechanical stability life (failure = 230 pen) as obtained for greases A, B, C, and D, in the conventional roll tester under normal test conditions and in the modified roll tester in the presence of radiation are presented in Figures 10, 11, 12, and 13. Grease A proved markedly superior to conventional greases and somewhat more stable than Greases B, C, and D in the irradiated roll test. Static tests with Grease B indicated that it was comparable in performance to Grease A. In dynamic tests, however, it proved slightly more susceptible to radiation damage. Grease C failed the dynamic test as predicted from static evaluations.

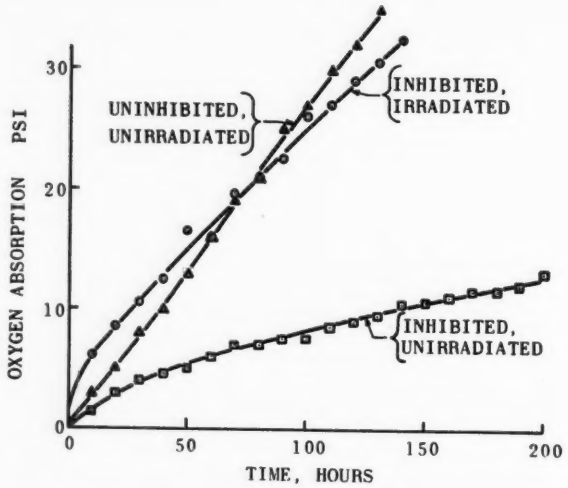


Figure 9. Oxygen absorption of inhibited and unihibited greases before and after irradiation.

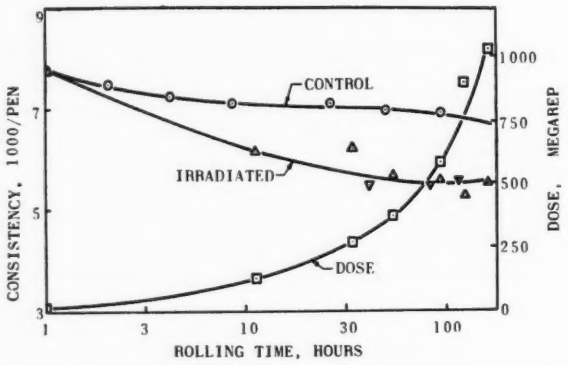


Figure 10. Grease A—Dye-Mineral Oil. Roll tests of grease A, mineral oil thickened with indanthrene. Each curve shown is a composite of tests of two different batches of this grease.

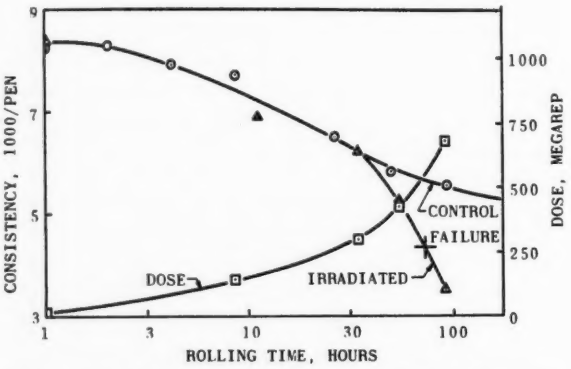


Figure 11. Grease B—Silica-Mineral Oil Roll tests of grease B. This grease is mineral-oil thickened with a hydrophobic silica.

Grease D, because of its soft initial consistency, failed the dynamic test before it had received a significantly damaging radiation dose.

Greases similar to those presented here are being tested in a number of applications to determine service limitations of this type of product. It is believed that

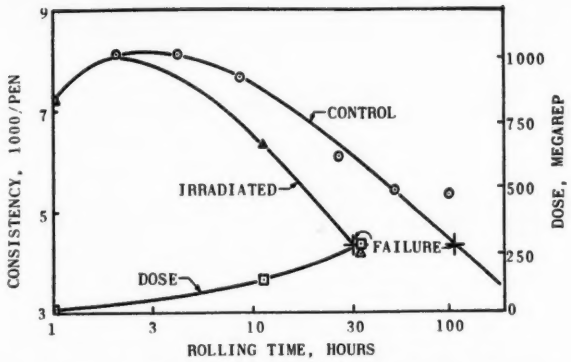


Figure 12. Grease C—Clay-Mineral Oil. Roll tests of grease C, the same mineral oil thickened with a clay.

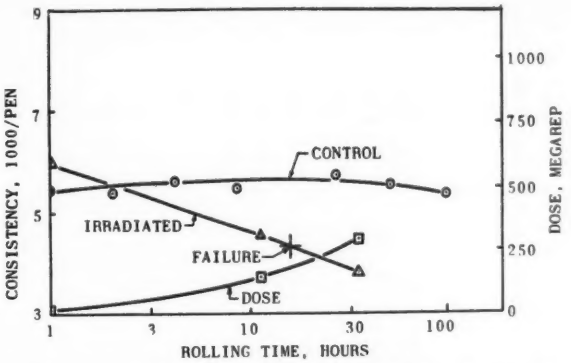


Figure 13. Grease D—Dye-Mineral Oil. Roll tests of grease D, mineral oil thickened with indanthrene. This grease was quite soft.

these greases will provide satisfactory performance at temperatures up to 300°F and at radiation fluxes up to 10^5 r per hr.

The dynamic testing described approaches service conditions in most respects except temperature. To include the latter, arrangements are being made to run experimental products in an irradiated bearing rig at elevated temperatures. Further improvements now under investigation include extending the temperature range of radiation-resistant greases and incorporating oxidation inhibitors that will survive high doses of radiation.

CONCLUSIONS

1. A modification of the Shell Roll Tester has been developed for the evaluation of greases in the presence of radiation, which has proved effective in selecting radiation resistant products.

2. The dyestuff indanthrene has proven extremely resistant to radiation damage, hence greases based on it are limited in performance only by the radiation and oxidation stability of the base oil.

ACKNOWLEDGMENTS

The authors wish to express their thanks to Dr. C. D. Wagner and Mr. V. A. Campanili of Shell Development Company for their help in planning and conducting the Van de Graaff irradiations.

The indanthrene dye used in this program was supplied by the General Dyestuff division of General Aniline and Film Corporation under the designation "Indanthrene Blue RS".

REFERENCES

1. J. G. Carroll, R. O. Bolt, and B. W. Hotten, "Radiation-Resistant Greases." *Lubrication Engineering* 13, March, 1957, 136-140. R. O. Bolt, J. G. Carroll, B. W. Hotten, and S. R. Calish, Jr., "Radiation Resistant Greases." USAEC Document AECU-3148, June 30, 1956.
2. J. G. Carroll and S. R. Calish, Jr., "Some Effects of Gamma Radiation on Commercial Lubricants." *Lubrication Engineering* 13, July, 1957, 388-392.
3. R. O. Bolt, J. G. Carroll, and S. R. Wright, "Radiation Resistant Lubricants—Their Development and Status." USAEC Document TID-5186 (Del.), June 30, 1954; declassified with deletions February 26, 1957.
4. B. W. Hotten and J. G. Carroll, "Radiation Damage in Lubricating Greases." *Industrial and Engineering Chemistry 50,* Feb. 1958, 217-20.
5. J. A. King and W. L. R. Rice, "The Effects of Nuclear Radiation on Lubricants." *Lubrication Engineering* 13, May, 1957, 279-283. W. L. R. Rice, "The Effects of Nuclear Radiation on Military Specification Greases." Wright Air Development Center Technical Report 56-430 (Part I), December, 1956.
6. W. L. R. Rice, "Nuclear Radiation Resistant Lubricants." Wright Air Development Center Technical Report 57-299, May, 1957.
7. H. A. Woods and H. M. Trowbridge, "Shell Roll Test for Evaluating Mechanical Stability." *NLGI Spokesman* 19, No. 5, August, 1955, 26-27, 30-31. J. D. Smith, "The Design and Use of the Shell Roll Test." *NLGI Spokesman* 19, No. 8, November, 1955, 8-10.
8. J. W. Armstrong and H. A. Woods, "Development of an Extreme High Temperature Grease." *NLGI Spokesman 22,* April 1958, 9-13.

5th Annual Joint Lubrication Conference

ASLE **ASME**

Make this year's conference a part of your vacation plans—special programs have been planned for the ladies attending with their husbands. Papers will cover wear, gas-lubricated bearings, gear lubrication, high temperature lubrication, new lubricants and their properties, lubrication of bearings exposed to radiation, and other related topics. Complete program available upon request in August.

Hotel Statler **October 13, 14 & 15, 1958** **Los Angeles, Calif.**

The Effect of Pressure and Molecular Weight Upon the Viscosity of Polybutenes

L. B. Sargent, Jr., Chief, Lubricants Division,
Alcoa Research Laboratories,
New Kensington, Pa.

Some measurements concerning the influence of molecular weight and molecular weight distribution upon the viscosities of polybutenes over a range of pressures are presented and discussed. A rolling-ball viscometer and conventional high-pressure equipment were used. The data indicate that average molecular weights of polybutene blends do not fully reveal the true nature of their viscosity properties. Polybutene blends consisting of components having widely different molecular weights behave, re viscosity, as though their average molecular weights are lower than measurements reveal.

The reaction-rate theory of viscosity indicates that both the average molecular weight and the molecular weight distribution of a polybutene are important in predicting viscosity behavior.

While the general knowledge that temperature and pressure affect the viscosities of fluids is well known, the precise details of these variations and the reasons for them are relatively obscure. This situation is more acute when synthetic fluids and pressure effects are considered because little information is available in this field with the exception of a few scattered measurements made incidentally to other investigations.

With the current need for lubricants having characteristics not possessed by petroleum oils; more incentive exists for developing an understanding of the viscosity behavior of these non-petroleum fluids as influenced by their environment, including temperature and pressure. Since the chemical natures of these synthetic liquids are more closely delineated than those of petroleum oils, these materials offer opportunities for determining the fundamental causes of their physical behavior. Once these causes are recognized, more fruitful usage will result and improved fluid lubricants will be obtained.

Since viscosity is a flow property, the size and structure of the molecules in the flowing liquid are partially responsible for the viscosity behavior. Because most fluid lubricants are complex mixtures of many different types of molecules, knowledge of the influence of molecular size and shape is most pertinent to a better understanding of this field.

The manner in which viscosity varies with pressure and temperature is partially dependent upon molecular size and configuration. Using polymers having the same chemical composition (polybutenes) but varying in average molecular weight and range of molecular weight distribution within a given polymer, measurements were made of the influence of pressure upon the viscosities of these polymers.

APPARATUS AND MATERIALS

The experimental data were obtained using a ball-and-slanted-tube (rolling ball) viscometer invented by Flowers (6) in 1914 and adequately described by Hersey and Shore (8), and Dow (4). A schematic diagram of the apparatus is shown as Figure 1.

The viscosity of the fluid being studied determines the time required for the calibrated ball to roll the length of the tube, which is filled with the fluid of interest. The tube is positioned in a fixture which provides accurate control of the angle at which the tube is inclined. The viscometer is contained in an electronically controlled constant-temperature oil bath. The metal ball rolling down the tube breaks and makes contact with insulated wires in the end plugs. This sequence of events activates a vacuum tube operated relay which in turn controls the action of an electric stop clock.

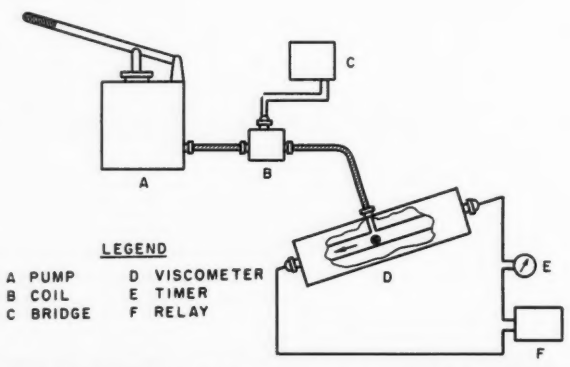


Figure 1. Schematic of rolling ball viscometer and auxiliary equipment.

Pressures were generated by a hydraulic hand pump which could be operated directly to about 20,000 psi and indirectly through an intensifier to about four times this pressure. All pressure fittings used in the system were of the conventional Bridgman (3) design. The pressure transmitting fluid and the test liquids were separated by means of a tight-fitting piston located adjacent to the viscometer. The pressures were measured by use of a coil of double-silk covered manganin wire wound non-inductively on a non-conducting spool. This coil was positioned in the pressure system at the end of a suitable plug. Since the change in electrical resistance of manganin with pressure is linear (3) and is negligible with temperature, a Carey-Foster bridge and lamp-and-scale galvanometer served to provide the necessary data once the coil had been calibrated. The resistance of the coil at atmospheric pressure was about 120 ohms. The coil calibration was accomplished by means of a dead-weight gage, and was carried out over the entire pressure range (atmospheric to 20,000 psi) of this investigation.

The subjects of this investigation are butylenes polymerized with the catalytic aid of BF_3 or $AlCl_3$ into fluids known as polybutenes. Some pertinent physical properties of these fluids are summarized in Table 1. All polymers used in these studies are Newtonian at a rate of shear of about 2000 $sec.^{-1}$ as indicated by the use of a rotary cone viscometer. Polybutenes 1, 2 and 3 are closely fractionated cuts taken by steam vacuum distillation from the lowest viscosity product of a polymerization unit. The molecular weight range in each of these products is very small ($\pm$ 5 percent). Polybutenes *A* and *B* are commercially available liquids made by blending two polymers (average molecular weights of 330 and 800) having wide differences in viscosity. Therefore, these materials have large molecular weight distribution ranges and the values for molecular weights reported in Table 1 are averages.

The molecular weights of these polybutenes were determined by the manufacturer using the ebullioscope of Barr, Anhorn and Hanson (1) after the manner reported by Menzies and Wright (9). The usual precision of these determinations is $\pm$ 0.8 percent average and $\pm$ 3 percent maximum. Since this technique furnishes number average molecular weights, the low molecular weight components dominate the mixtures in much the same way as in viscosity values, thus aiding in the mutual correlation of these data.

TABLE 1. PHYSICAL PROPERTIES OF POLYBUTENES AT ATMOSPHERIC PRESSURE

	1	2	3	A	B
Viscosity (cp)					
at 77°F	70.0	128.1	239.1	201.4	132.9
100°F	33.9	56.5	98.1	90.7	61.1
210°F	4.22	5.50	7.41	8.37	6.76
Viscosity Index	25.	24.	25.	74.	81.
ρ at 77°F (g/ml)	0.8315	0.8352	0.8394	0.8408	0.8426
80°F	0.8311	0.8348	0.8382	0.8395	0.8413
140°F	0.8102	0.8144	0.8185	0.8197	0.8206
Mol. Wt.*	372	400	429	420	396

*Determined by manufacturer.

The two commercial fluids were chosen because their average molecular weights closely matched those of two of the carefully fractionated polymers. The influence of molecular weight distribution upon the variation of viscosity with temperature can be observed in Table 1 by reference to the viscosity indices. These values indicate that the viscosities of the blends (wide molecular weight range) are influenced by temperature changes to a lesser degree than are the viscosities of the distilled fractions. The viscosity values reported in Table 1 were determined with the use of calibrated Cannon-Fenske pipettes of the Ostwald type.

EXPERIMENTAL PROCEDURE

All parts of the viscometer which come in contact with the experimental fluid are thoroughly cleaned and dried. The experimental fluid is placed in the system; care is taken to allow trapped air to escape; and the sealed viscometer is then placed in the constant temperature bath. After the desired temperature and pressure have been obtained, sufficient time is allowed for the dissipation of the heat of compression of the fluid. The viscometer is tilted and the data collected. Several roll times at each pressure and temperature are recorded and averaged. These are generally repeatable at any pressure and temperature with an error of less than one percent. The ball roll time in seconds and the Carey-Foster bridge measurements are converted into absolute viscosity and pressure respectively by the use of the proper constants and equations.

Although the motion of the sphere in a rolling ball viscometer has not succumbed to an exact theoretical treatment, Hersey (8) has shown, from dimensional analysis, that

$$\mu = K(\rho_s - \rho_f)t \qquad [1]$$

providing the roll time, t, is sufficiently long. Therefore, the viscosity, μ, is directly proportional to the roll time. The constant, K, is obtained by calibration of the viscometer with a fluid of known viscosity. ρ_s and ρ_f are the densities of the sphere and fluid, respectively. The empirical equation of Dow and Fink (5)

$$\rho_f = \rho_0(1 + mp - np^2)_t \qquad [2]$$

was used to calculate the fluid densities as a function of pressure. In [2], ρ_f is the fluid density at the temperature, t, and pressure, p, of the experiment; ρ_0 is the fluid density at atmospheric pressure and temperature t; m and n are empirical constants.

RESULTS AND THEORY

The pressure-viscosity data at 80°F and 140°F in Tables 2 and 3 were obtained from smooth curves drawn through large scale plots of the experimental data. These data were then recalculated and plotted in Figures 2 and 3 as isothermal relative viscosities (μ_p/μ_0) against pressure.

TABLE 2. PRESSURE-VISCOSITY DATA FOR POLYBUTENES AT 80°F

PRESSURE, PSI	VISCOSITY, cp				
	1	2	3	A	B
15	66.5	116.8	226.0	204.0	117.2
1000	87.3	153.	300.	268.	149.
2000	112.	198.	398.	348.	190.
4000	176.	330.	674.	578.	302.
6000	275.	537.	1130.	940.	478.
8000	430.	860.	1860.	1500.	740.
10000	668.	1360.	3020.	2400.	1130.
12000	1040.	2130.	4850.	3730.	1700.
14000	1560.	3330.	7650.	5800.	2500.
16000	2250.	—	—	—	—

TABLE 3. PRESSURE-VISCOSITY DATA FOR POLYBUTENES AT 140°F

PRESSURE, PSI	VISCOSITY, cps				
	1	2	3	A	B
15	12.53	18.45	28.96	30.45	21.40
1000	15.1	22.5	36.4	37.4	26.0
2000	18.1	27.4	45.0	45.3	31.3
4000	25.9	40.3	67.0	67.0	45.0
6000	36.8	58.8	99.5	98.0	64.0
8000	51.8	84.4	144.	142.	88.0
10000	72.2	122.	207.	203.	122.
12000	98.7	168.	300.	290.	165.
14000	136.	238.	428.	417.	223.
16000	187.	331.	—	—	—
18000	258.	462.	—	—	—
20000	353.	—	—	—	—

The data presented indicate that molecular weight distribution in a polybutene definitely influences the pressure coefficient of viscosity. The average molecular weight therefore is not a reliable criterion by itself with which to predict the variation of viscosity with pressure changes. Knowledge concerning the distribution of molecular weight is also required. Thus Figures 2 and 3 indicate that polybutene A has pressure-viscosity characteristics very similar to polybutene 2 even though its average molecular weight is more closely equivalent to that of polybutene 3. Likewise, polybutene B has a pressure-viscosity behavior approximating that of polybutene 1 even though its molecular weight is roughly equivalent to that of polybutene 2. These blended materials (A and B) behave, as far as pressure-viscosity effects are concerned, as though their molecular weights were actually less than measurements reveal. This indicates a more facile movement of molecules than would occur in a molecularly-uniform equivalent molecular weight fluid.

The reaction rate theory of viscosity (7) has been applied with reasonable success by other workers to the viscosity-pressure effect. Attempts to correlate the viscosity-pressure effect with many different physical properties of fluids have met, however, with varying degrees of success for reasons which will be

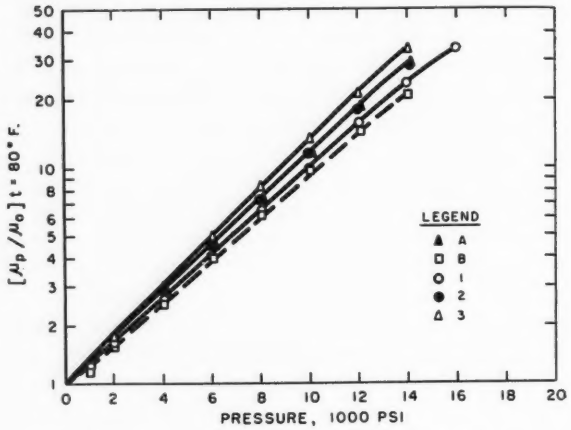


Fig. 2. Relative viscosities of polybutenes at 80°F and various pressures.

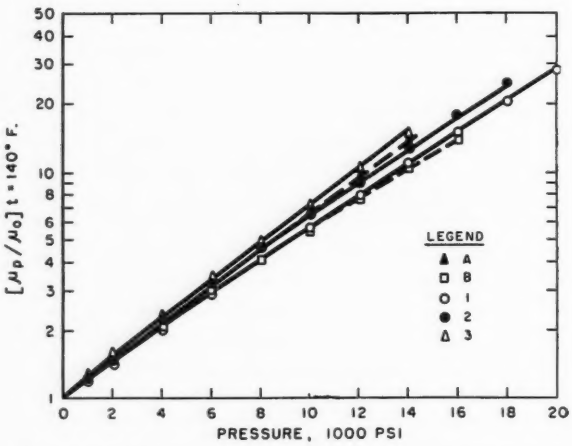


Figure 3. Relative viscosities of polybutenes at 140°F and various pressures.

mentioned later. Most of these investigations have been hampered by the use of petroleum oils or other equally complex fluids, which are not representative of single molecular species. Therefore, from a theoretical viewpoint, these correlation attempts can hardly be valuable and future ones must consider fluids of known structure and chemical composition, and of a single molecular species.

Bondi (2) has utilized the reaction rate theory in a simplified form to describe the theoretical viscosity behavior of fluids under the influence of pressure and temperature. By the use of these functions, a relative idea of the influence upon viscosity of molecular weight and molecular weight distribution range within a synthetic polymer may be obtained. These relationships are used to describe the viscosity behavior of the polybutenes used in this investigation.

The differences among the many theories of viscosity which exist are attributed mainly to the model of the liquid state chosen, or the method of analysis of the elemental flow process. Most of these theories do, however, lead ultimately to similar formu-

lations for the pressure and temperature coefficients of viscosity.

$$\Delta H_{\ddagger} = R\left[\frac{\partial \ln \nu}{\partial(1/t)}\right]_p \quad [3]$$

$$\Delta V_{\ddagger} = Rt\left(\frac{\partial \ln \nu}{\partial p}\right)_t \quad [4]$$

$$\mu = Ae^{\Delta F_{\ddagger}/Rt} \quad [5]$$

In the above equations,

$\Delta H_{\ddagger}$ = temperature coefficient of viscosity
$\Delta V_{\ddagger}$ = pressure coefficient of viscosity
$\Delta F_{\ddagger}$ = free energy of activation for flow
ν = kinematic viscosity
μ = absolute viscosity
R = universal gas constant
t = temperature
p = pressure
A = constant

In the theoretical model chosen to describe the flow process in this discussion, $\Delta H_{\ddagger}$ is also the total heat of activation for flow and $\Delta V_{\ddagger}$ is also a measure of the hole size necessary for flow to occur. Thus, $\Delta H_{\ddagger}$ and $\Delta V_{\ddagger}$ are both dependent upon chemical structure and therefore preclude any possibility of correlating the temperature and pressure coefficients of viscosity of a wide range of fluids.

The previously described functions are used in this investigation to indicate the influence of molecular weight variation within polybutene polymers upon their viscosity behavior. Table 4 presents the pressure and temperature coefficients of the polybutenes described herein along with those of some miscellaneous fluids from Bondi (2). The values of $\Delta V_{\ddagger}$ in Table 4 indicate that the relationship between $\Delta V_{\ddagger}$ and average molecular weight for the polybutene blends (A and B) differs from that for the polybutene fractions (1, 2, 3.) All other functions depending upon $\Delta V_{\ddagger}$ exhibit a similar dependence upon molecular weight distribution. Significantly, the functions which are temperature-dependent do not show this deviation.

Figure 4 presents examples of the variation of $\Delta V_{\ddagger}$ of the polybutenes with average molecular weight and pressure. This graph indicates that the polymer blends and the fractionated polymers exhibit viscosity behaviors which are not consistently representative of the average molecular weights. Thus, $\Delta V_{\ddagger}$ is not a direct function of the average molecular weights of the blends.

TABLE 4. PRESSURE AND TEMPERATURE COEFFICIENTS OF VISCOSITY

	TEMP. °F	MOL. WT.	$\Delta H_{\ddagger}$, KCAL	$\Delta V_{\ddagger}$, ML	$\Delta V_{\ddagger}/V$	$\Delta V_{\ddagger}/\Delta H_{\ddagger}$
Polybutene 1	78.8	372	9.77	95.9	0.214	9.81
Polybutene 2	78.8	400	10.8	98.6	.206	9.10
Polybutene 3	78.8	429	12.1	104.	.204	8.63
Polybutene A	78.8	420	11.2	94.1	.188	8.42
Polybutene B	78.8	396	9.96	86.8	.184	8.72
Mineral Oil	100.	—	8.0	56.	.181	7.0
Silicone	77.	1300	3.23	30.	.023	9.3

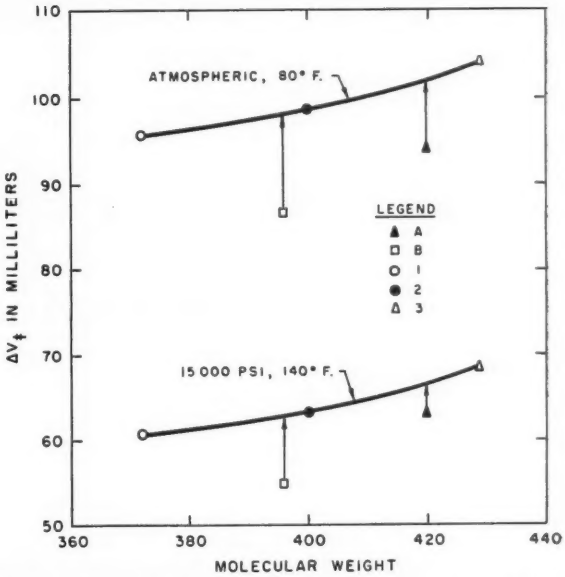


Figure 4. Pressure coefficient of viscosity vs molecular weight of polybutenes.

The relatively high values of $\Delta H_{\ddagger}$ for the polybutenes indicate that these highly branched molecules are very rigid. The silicones, on the other hand, are more flexible because of the larger atomic radius of silicon and the high mobility around the Si–0 bond. The most desirable fluids, where temperature-viscosity constancy is important, are those possessing low $\Delta H_{\ddagger}$ values as these indicate a viscosity relatively less sensitive to temperature changes (high viscosity index).

These investigations substantiate the belief that the molecular weight range within a Newtonian polymer is as important for viscosity considerations as the average molecular weight. The techniques used in this investigation are shown to be useful in elucidating the roles of structure and molecular weight upon the viscosity behavior of polybutenes. Furthermore, the importance of including investigations of the effect of pressure upon viscosity in these fields is emphasized.

CONCLUSIONS

The following conclusions are restricted to the materials of this investigation and to the pressure and temperature ranges described.

1. The viscosity behavior of polybutenes is dependent upon both average molecular weight and molecular weight range.

2. Polybutenes consisting of components differing widely in molecular weight behave from a viscosity viewpoint as though their average molecular weights are less than measured.

(*Continued on p. 309*)

A Radiotracer Approach to the Study of Engine Valve Train Lubrication

M. J. Furey and J. F. Kunc, Jr.,
Products Research Division,
Esso Research and Engineering Company, Linden, N. J.

Radioactive tracers have been used to demonstrate how lubricating oil composition and engine operating variables affect valve-train wear in automobile engines. A technique for measuring this wear in an engine equipped with radioactive valve lifters is described and results of studies on wear rates, metal transfer, and the nature of the wear debris are presented. With this technique, valve-lifter wear can be determined accurately, rapidly, and continuously under normal conditions of engine operation. Also presented are the results of experiments made with radioactively tagged zinc dialkyl dithiophosphate to shed additional light on the mechanism by which this lubricant additive reduces valve train wear.

The fact that radioactivity can be induced in a wide variety of materials by simply exposing them to neutron bombardment in a nuclear reactor has placed a host of very valuable tools at the disposal of the research worker to aid him in solving problems. Advantage has been taken of this fact by a number of workers interested in investigating wear and lubrication of objects moving in contact with one another. Thus, piston rings made radioactive by exposure in a nuclear reactor have been used widely to study piston ring lubrication and wear (1-11). Similarly, results of wear studies made with radioactive gears have been reported (12-15). As will be demonstrated in the present paper, radiotracer techniques are extremely useful for wear and lubrication studies involving valve lifters and cam lobes of poppet valve engines. The techniques used for studying this type of wear and a review of representative results obtainable by their application are described in this paper.

FUNCTION OF THE VALVE TRAIN

A diagram of a typical valve train mechanism for a V-type gasoline engine is shown in Figure 1. The purpose of the valve lifters and cams is to open and close the engine valves at the proper time. This is done by converting the rotary motion of the crankshaft into a reciprocating motion of the valves. Although the type of motion between the rotating cam and valve lifter is complex, it is essentially a sliding action. The forces acting on the cam/lifter region include (a) the force of the valve spring acting through the rocker arm and push rod, (b) the dynamic forces resulting from accelerations in the system, and (c) the hydraulic force of oil in the valve lifters. The curvature of the cam, particularly at the cam nose, leads to very high contact stresses between the cam and the valve lifter. These stresses have been calculated to be from 50,000-100,000 pounds per square inch and sometimes more

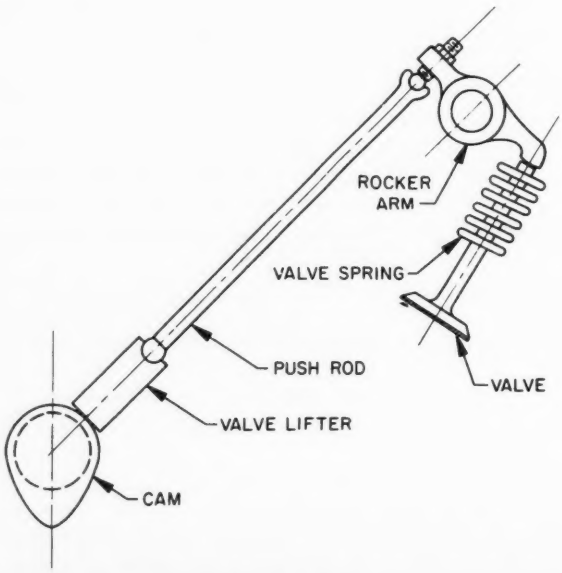


Figure 1. Valve train—V-Type engine.

(16). Lubrication of the cams and lifters is chiefly by oil splashed into the area by the connecting rods and leakage from the holes which feed oil to the valve lifters. With oils of normal viscosity, full hydrodynamic lubrication is not achieved and metal-to-metal contact occurs.

DEVELOPMENT OF A WEAR TEST USING RADIOACTIVE VALVE LIFTERS

Research on valve train wear has been handicapped by the lack of a suitable short-time test. None of the common laboratory load-carrying or wear tests are satisfactory for predicting the valve train wear properties of an oil in an engine. However, some success has been realized in the development of laboratory engine tests for measuring this wear. In these tests, wear is determined by direct measurements of the parts. To obtain enough wear for accurate measurements, however, the engines must be run either for long periods (e.g., 50 to 100 hours) or under exaggerated operating conditions (e.g., overloaded valve springs). In either case, the engines must be torn down between tests, and this is both time-consuming and costly.

In the present study, the use of radioactive valve lifters in an engine has been investigated as a method of determining wear. As will be shown in greater detail later, this technique avoids many of the drawbacks associated with engine tests used heretofore for studying valve train wear.

The engine used in this study was of the V-8 overhead valve type having a displacement of 331 cubic inches. This particular engine has carburized steel (SAE 5120) valve lifters and an alloy cast iron camshaft. A set of sixteen completely assembled valve lifters were made radioactive by exposure to neutrons at a flux density of about 2×10^{11} neutrons/cm^2 sec. for one week in a nuclear reactor. This resulted in an Fe-59 activity of approximately 0.01 millicuries per gram of metal, or roughly 1 mc/lifter. The lifters to be irradiated were checked for abnormal operation on the basis of leak-down rates in oil and then cleaned in heptane to remove the oil. A disc-shaped segment removed from the wearing surface or face of a valve lifter was also irradiated for use in preparing a standard radioactive solution. The radioactive valve lifters were individually loaded with oil and installed in the engine with the aid of long-handled tongs. To keep the radiation level low during the installation, iron bricks were placed in the push rod chamber directly on top of the lifters. After the engine was completely reassembled, it was found that the engine itself served as an excellent shield against radiation and that no extra shielding was required at this activity level.

Sampling and Counting Procedures

The Fe-59 formed by neutron capture serves as a tracer for the metal, emitting gamma rays and decaying with a half-life of 47 days. In engine tests with the radioactive valve lifters, wear is determined by using radioisotope counting techniques to follow the concentration of the wear debris in the crankcase lubricant. There are several ways in which this can be done, using either sampling or continuous monitoring methods with any one of a variety of radiation detectors. The method used in the present study is shown schematically in Figure 2. As the engine is operated, radioactive debris resulting from wear of the lifters accumulates in the crankcase oil. Samples of this oil are taken periodically from the crankcase and counted with a scintillation detector connected to a scaler. The scintillation counter has the advantage of being generally more efficient for counting energetic gamma rays than a Geiger counter. After being counted, each sample is returned to the engine. Similarly, a standard solution containing a known weight of a radioactive valve lifter is also counted. From this, the concentration of lifter wear debris in the oil sample is calculated.

To prevent removal of the radioactive wear debris from the oil during the course of a test, the oil filter normally used in the engine is removed. It is assumed that the minute amount of wear debris forming in a short-time test has no effect on the rate of valve lifter wear. The engine is flushed thoroughly between tests to insure the recovery of all the wear debris.

Advantages of the Radioactive Valve Lifter Test

The test with radioactive valve lifters has several advantages over engine tests in which wear is determined by measuring the length of the valve lifters. Many of these advantages stem from the fact that a few millionths of a gram of valve lifter wear can be measured accurately. The advantages resulting from this high sensitivity are:

(a) Wear data can be obtained more rapidly and at less expense than by other engine test methods. This results from two factors. First, only a few hours of engine operation are required to obtain accurate wear data. Second, it is not necessary to disassemble and reassemble the valve train between individual tests.

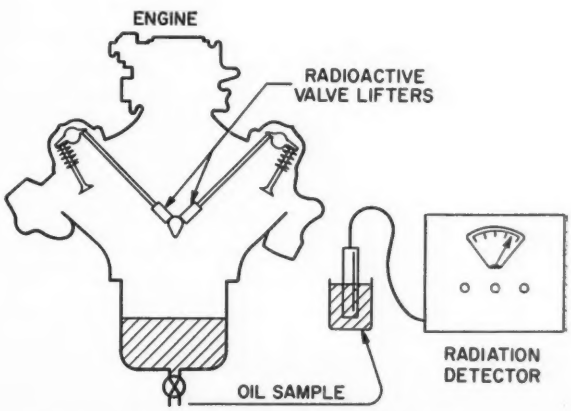


Figure 2. Use of radioactivity to measure valve lifter wear.

(b) There is no need to use exaggerated operating conditions (excessive spring loads, etc.) to shorten the period of the test. The use of normal operating conditions results in data which can be used with greater confidence.

(c) Since only a small amount of metal is removed in each test, a sizable number of runs can be made with a single set of lifters. This eliminates the many uncertainties arising from metallurgical variations which are introduced when new lifters and a new camshaft are used in each test.

(d) In each test, lifter wear can be measured continuously with time without stopping the engine. This is useful for studying the rate of lifter wear during warm-up, immediate effects of changing engine operating conditions, and unusual wear behavior of lubricants as a function of time.

(e) The short test period permits the evaluation of unusual lubricant compositions which could not be tested for longer periods of time because of danger of engine failure.

The use of radioactive lifters also gives rise to advantages other than those based upon the sensitivity of the wear tests. With this technique, it is possible to determine if metal transfer from the valve lifter to the camshaft takes place. Since the wear debris which results from these tests is radioactive, studies on its chemical and physical characteristics are facilitated. These advantages are important in conducting studies of the mechanism by which valve train wear takes place.

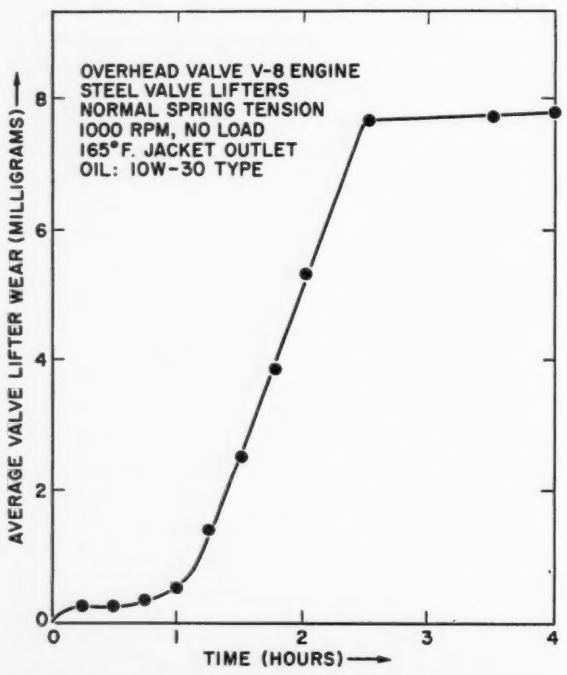


Figure 3. Break-in of radioactive valve lifters.

Wear as a Function of Time

After being installed in the engine, the valve lifters were "broken in" by operating the engine for four hours at 1000 rpm and at no load with the jacket outlet temperature controlled to 165°F. Wear as a function of time for a break-in period is shown in Figure 3. It can be seen that during the first hour of engine operation, wear is relatively low. This is followed by a high wear rate which quite abruptly decreases to a low constant value.

Plots of wear against time for typical high, medium, and low wear oils are presented in Figure 4. These curves were obtained on valve lifters which were broken in after being installed in the engine. In Figure 4, it can be seen that the wear is again low with each of the three oils during the first hour of engine operation. From this point on, the curves diverge according to the wear characteristics of the lubricant. With each of the oils, however, wear after the first hour becomes essentially linear with time. The low valve lifter wear observed initially may be the result of the lower oil temperatures with consequent higher oil viscosities prevailing during the period of engine warm-up.

Sensitivity to Changes in Engine Operating Variables and Lubricant Composition

To be useful for studying valve train lubrication, a test must give wear results which are sensitive to

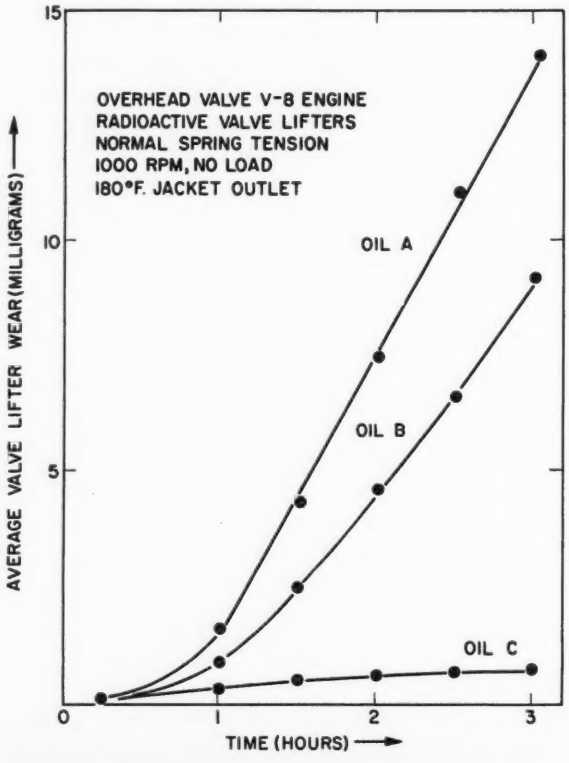


Figure 4. Valve lifter wear as a function of time.

changes in engine operating variables and to differences in lubricant composition which are known to influence this wear. The test with radioactive valve lifters is satisfactory in both these respects. It was found that both the jacket water temperature and engine speed have pronounced effects on the rate of valve lifter wear, whereas merely stopping and starting the engine has little effect. This is shown in Table 1 where it is seen that increasing the jacket outlet temperature from 100°F to 180°F at 1000 rpm more than doubles valve lifter wear. Furthermore, wear per camshaft revolution is much less at 2000 rpm than at 1000 rpm.

TABLE 1. EFFECT OF OPERATING VARIABLES ON VALVE LIFTER WEAR
Two-Hour Tests

JACKET OUTLET TEMPERATURE (°F)	ENGINE SPEED (rpm)	TYPE OF OPERATION	OIL SUMP TEMPERATURE (°F)	RELATIVE VALVE LIFTER WEAR PER CAMSHAFT REVOLUTION
100	1000	Continuous	130	100
100	1000	Cyclic[1]	130	123
180	1000	Continuous	186	211
180	1000	Cyclic	186	210
100	2000	Continuous	163	43

[1]A five-second shutdown every five minutes.

The effect of engine speed on valve lifter wear observed in these tests is in agreement with field data. This is shown in Table II where wear data obtained in the laboratory engine at two speeds are compared with the results of a field test in which the same lubricant, car make, and valve train metallurgy were employed. The wear in terms of weight loss in the radioactive test was converted to a decrease in lifter length from the cross-sectional area and density of the valve lifters, assuming uniform wear.

TABLE 2. EFFECT OF SPEED ON VALVE LIFTER WEAR IN THE FIELD AND RADIOACTIVE TESTS

	FIELD TEST		RADIOACTIVE LIFTER WEAR TEST[3]	
Engine Speed (rpm)	800[1]	2180[2]	1000	2000
Average Lifter Wear/1000 Miles (Inches × 10^4)	14.3	5.9	8.3	3.5

[1]City and intercity driving for 9000 miles at an average speed of 22 mph.
[2]High speed (60 mph) driving for 3000 miles.
[3]Two hours at 100°F jacket outlet temperature.

The sensitivity of the radioactive valve lifter test to differences in lubricant composition was demonstrated by tests run on two oils which gave widely different levels of wear in the field. The results of the field and laboratory tests on these oils in the same engine are shown in Table 3. It is seen that the laboratory test carried out at 1000 rpm, no load, and 180°F. jacket outlet temperature produces approximately the same wear rate as that observed in the field.

TABLE 3. FIELD VS RADIOACTIVE VALVE TRAIN WEAR TESTS

	LIFTER WEAR/1000 MILES (INCHES × 10^4)	
LUBRICANT	FIELD TEST [1]	LABORATORY RADIOACTIVE
I	1	3
II	14	16

[1]City and intercity driving for 9000 miles at an average speed of 22 mph.

Test Conditions For Evaluating Lubricants

Based on the results fo the preliminary test work conducted, the following operating conditions were selected for use in the multicylinder engine to study the valve train wear properties of various lubricants.

TEST CONDITIONS, RADIOACTIVE VALVE-LIFTER WEAR	
Engine Speed	1000 rpm
Engine Load	Zero
Jacket Water Outlet Temperature	180°F
Oil Temperature (Uncontrolled)	180-190°F
Time	3 Hours

Each test consists of three phases:

(a) An initial flush of the engine with 4 quarts of the test oil for 10 minutes at 1000 rpm followed by a 20-minute drain.

(b) Three hours of operation of the engine under the stated operating conditions with 5 quarts of a new charge of the same test oil followed by a 20-minute drain.

(c) A final flush with 4 quarts of a non-additive base mineral oil for 5 minutes at 1000 rpm followed by a 20-minute drain.

Using this test procedure, it has been found that the amount of radioactive wear debris in the initial flush is negligible. This indicates that the final flush from the previous test is thorough. The valve lifter wear is calculated from the total amount of radioactive wear debris contained in the oil from (a) the three-hour test and (b) the final flush. Since the amount of wear occurring during the final five-minute flush is negligible, it is disregarded in the calculations.

Trend in Wear Tests

Periodic reference tests are made with a given lubricant. The results of these tests show a slight gradual decrease in valve lifter wear, at least during the first 50 hours of operation after the engine is broken in. The results of individual wear tests are corrected to take this trend into account. An example of the trend is shown in Table 4.

TABLE 4. TREND IN RADIOACTIVE VALVE LIFTER WEAR TESTS

TEST	RELATIVE VALVE LIFTER WEAR
1	100.0
5	94.2
10	87.0
18	79.9

The decrease is rather small, amounting to about 1.5 percent per three-hour test. It may be due to a reduction in contact stresses resulting from the gradual rounding off of the cam nose as wear occurs.

EFFECT OF SOME LUBRICANT ADDITIVES ON VALVE LIFTER WEAR

Zinc salts of dialkyl dithiophosphoric acids have been shown to be particularly effective in reducing wear in the steel valve lifter/alloy cast iron camshaft system used for the present wear studies (16-18). The general formula for these salts is $[(RO)_2\ PSS]_2\ Zn$ where R is the alkyl group. Results of tests with radioactive valve lifters confirm the effectiveness of this particular type of zinc compound. As shown in Table 5, zinc di(C_6)alkyl dithiophosphate very markedly reduces lifter wear with a variety of lubricants.

TABLE 5. EFFECT OF ZINC DIALKYL DITHIOPHOSPHATE ON VALVE LIFTER WEAR

LUBRICANT	A	B	C
Relative Valve Lifter Wear			
Base lubricant alone	100	138	116
With 1.3 wt. % $[(RO)_2PSS]_2Zn$[1]	12	7	17

[1] Derived from the alcohol 4-methyl-2-pentanol.

The effects of other lubricant additives on valve lifter wear have also been studied with the radioactive test. For example, using this method it was found that the zinc portion of zinc dialkyl dithiophosphate is not essential for low wear. Experiments show that the nickel and iron salts are at least equal to the zinc additive in reducing lifter wear. The free dialkyl dithiophosphoric acid is partially effective but not as potent as the metallic salts. These compounds were all derived from the same alcohol, 4-methyl-2-pentanol, and were used in concentrations to equal the phosphorus and sulfur contributions of 1.3 wt. percent zinc dialkyl dithiophosphate. The results of these wear tests are shown in Table 6.

TABLE 6. EFFECT OF VARIOUS DIALKYL DITHIOPHOSPHATES ON VALVE LIFTER WEAR

LUBRICANT ADDITIVE	RELATIVE VALVE LIFTER WEAR
None	138
Zinc dialkyl dithiophosphate	7
Nickel dialkyl dithiophosphate	2
Ferric dialkyl dithiophosphate	6
Dialkyl dithiophosphoric acid	30

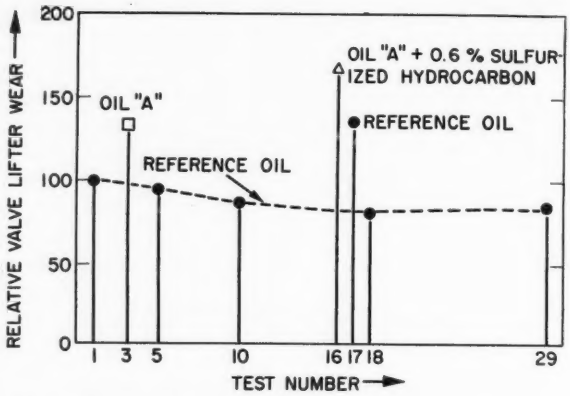


Figure 5. Carry-over effect on valve lifter wear.

Carry-over Effects

In some cases, carry-over effects on valve lifter wear exist from one test to the next. An example of this is shown in Figure 5. Here it is seen that the addition of a sulfurized hydrocarbon to Oil "A" not only increased valve lifter wear but caused the wear in the subsequent test (Reference Test 17) to be much higher than expected. Another reference test following this, however, gave normal results.

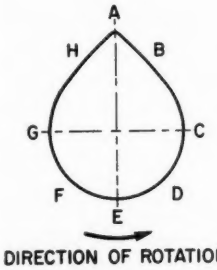
The particular sulfurized hydrocarbon used in this case is an effective E-P or extreme-pressure additive for metal cutting fluids. It is conceivable that this material reacts with the cam and valve lifter surfaces to form a non-permanent film, thereby causing a type of corrosive wear. The formation of this film and/or any roughening of the metallic surfaces which may have resulted from chemical attack might explain the high apparent rate of wear in the subsequent test.

METAL TRANSFER BETWEEN THE LIFTERS AND THE CAMSHAFT

Another advantage accruing from the use of radioactive valve lifters is that it is possible to study metal transfer and thereby learn more about the wear process itself. In this study, definite evidence has been obtained that metal is transferred from the valve lifters to the camshaft of an operating engine. This is based on the examination of a camshaft taken from the multicylinder engine which had been run against radioactive valve lifters on various lubricants for a total of 28 hours. Using a thin window Geiger tube (⅜-inch diameter), it was found that lifter metal is transferred to a specific area on the tip of each of the cam lobes. This is the region of greatest wear. In this study, the Geiger tube was placed 1/10-inch away from the area to be studied. Other areas were shielded with lead foil. Data for various locations on a typical cam lobe are given in Table 7.

The metal transfer probably results from welding or adhesion of asperities on the valve lifters and the cams. This conclusion is supported by the data in Table 8 which show that the transferred metal

TABLE 7. VARIATION IN METAL TRANSFER ON A GIVEN CAM LOBE



LOCATION	AMOUNT OF LIFTER METAL DETECTED (NET COUNTS/MINUTE)[1]
A (Nose)	14.3 ± 0.8[2]
B	1.1 ± 1.0
C	0.4 ± 0.7
D	0.4 ± 0.7
E	0.4 ± 0.7
F	0.4 ± 0.7
G	0.4 ± 0.7
H	1.2 ± 1.0

[1] After being rinsed in hexane.
[2] Only location showing significant amount of valve lifter metal.

cannot be removed by vigorous scrubbing with hexane, acetone, or water.

TABLE 8. EFFECT OF SOLVENTS ON VALVE LIFTER METAL TRANSFERRED TO CAMSHAFT

SUCCESSIVE TREATMENT OF CAM NOSE	RELATIVE AMOUNT OF METAL TRANSFERRED TO CAM NOSE (NET COUNTS/MINUTE)
Hexane rinse	14.3 ± 0.8
1st scrub in acetone	12.8 ± 0.8
2nd scrub in acetone	12.8 ± 0.8
Scrub in water	12.8 ± 0.8

As seen in Figure 6, the localization of transferred metal on the cam nose was also observed in autoradiographs made by wrapping X-ray film around the individual cams. Although the autoradiographs thus made were somewhat lacking in definition, there was no question that transferred metal was present in a narrow band (about 1/16-inch wide) on each cam nose parallel to the camshaft axis. It is estimated that the amount of lifter metal transferred to the cams in this particular case was of the order of 20-60 millionths of a gram.

The location of the transferred valve lifter metal on the cam nose would be expected on the basis of calculations* of the contact pressures existing between the cam and lifter in the engine under the operating conditions used. These calculations show that pressures at the cam nose are about 2-½ times as great as those at the base circle (roughly 100,000 vs 40,000 psi).

* Calculated from the Hertz formula

$$S = 0.591 \sqrt{\frac{\Sigma W}{br\ (1/E_1 + 1/E_2)}}$$

Where S = Stress or pressure, psi
ΣW = Total load, lb
b = Cam width, inches
r = Instantaneous nose radius, inches
E_1, E_2 = Elastic moduli of contacting materials, psi

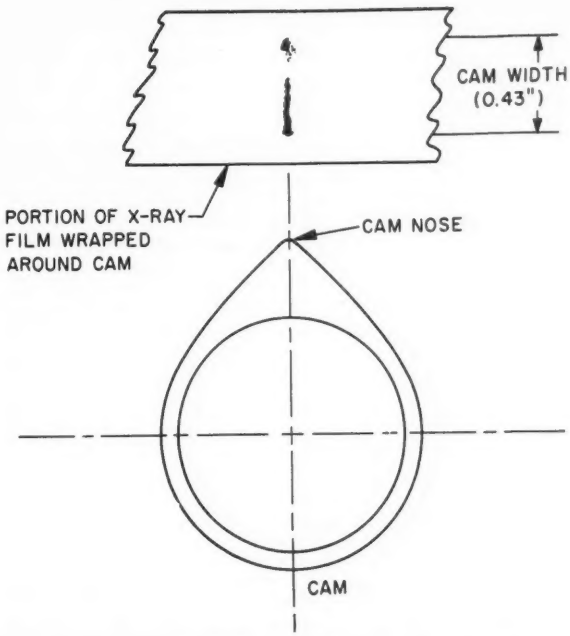


Figure 6. Autoradiograph showing metal transfer from a valve lifter to a cam.

NATURE OF THE VALVE LIFTER WEAR DEBRIS

When using radioactive valve lifters for studying wear, a good deal of information concerning the nature of the wear debris can be rather easily obtained. Using radioisotope counting techniques, a number of experiments were conducted on the lifter wear debris contained in a representative used oil at the conclusion of a test in the engine equipped with radioactive valve lifters.

Results of calculations of the size distribution of the valve lifter wear debris, made on the basis of settling rates, are summarized in Figure 7. It is seen that well over 90 percent of the wear debris particles were smaller than 6 microns in diameter and that 45 percent of the particles were less than 1 micron in diameter.

Experiments with the used oil also showed that none of the radioactive wear debris was soluble in water. Thus, none of the lifter wear debris was in the form of iron chlorides, nitrates, sulfates or other water-soluble salts, thereby suggesting that corrosion by the acid gases of combustion is not an important factor under the test conditions employed.

It was also found that one-third of the radioactive wear debris present in the used oil was extractable magnetically. This must therefore have been present in the form of iron particles and/or magnetite (Fe_3O_4) at the time the study was made. The existence of particles of lifter metal in the used oil indicates that a physical process such as the breaking off of metal peaks or welding is involved in valve train wear. A good deal of the valve lifter wear debris is indicated to be present in the form of non-magnetic iron oxides.

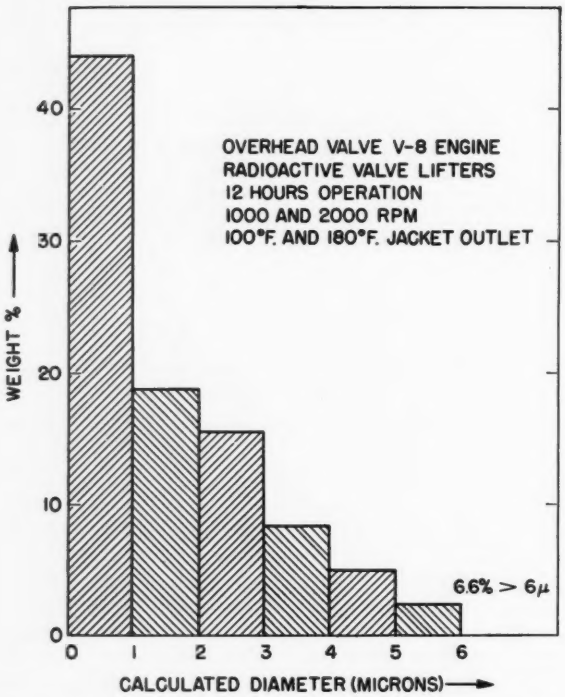


Figure 7. Size of valve lifter wear debris calculated from settling rates.

Whether these oxides formed directly on the lifter surfaces and subsequently were removed, or whether they represent metallic iron particles torn from the surfaces and later converted to oxides, is not known.

EXPERIMENTS WITH RADIOACTIVE ZINC DIALKYL DITHIOPHOSPHATE

Additives tagged with radiotracers can also be used to good advantage to study metal surface reactions and their possible relationship to lubrication. Initial experiments have been made with zinc dialkyl dithiophosphate containing radioactive zinc (Zn-65). This labeled additive will hereafter be referred to as *Zn* DDTP*. Results of tests in which polished steel specimens were immersed in a 2 percent solution of Zn* DDTP in hexane for 10 minutes at room temperature are shown in Table 9. These data reveal that an appreciable amount of Zn is strongly held by the steel surfaces even after repeated rinses in various organic solvents. Counting of the Zn-65, which emits gamma rays and has a half-life of 250 days, was carried out using a well-type scintillation counter.

From the activity of known weights of Zn* DDTP, it is calculated that the amount of zinc remaining on the metal surfaces is equivalent to over 100 molecular layers of zinc dialkyl dithiophosphate.

Experiments with blends of Zn* DDTP in white oil show that the retention of zinc by steel surfaces increases with time, concentration, and temperature. These results are presented in Table 10. The effects of time and concentration are shown in more detail in Figure 8.

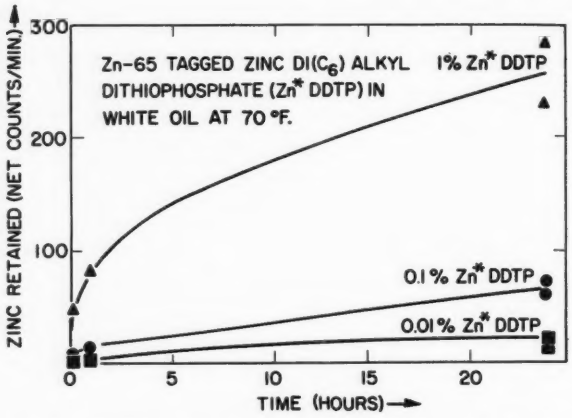

Zn-65 TAGGED ZINC DI(C6) ALKYL DITHIOPHOSPHATE (Zn* DDTP) IN WHITE OIL AT 70 °F.
1% Zn* DDTP
0.1 % Zn* DDTP
0.01 % Zn* DDTP
ZINC RETAINED (NET COUNTS/MIN.)
TIME (HOURS)

Figure 8. Effect of time and concentration on retention of zinc by steel.

TABLE 9. EFFECT OF VARIOUS ORGANIC SOLVENTS ON THE RETENTION OF Zn* FROM Zn* DDTP BY STEEL

TREATMENT OF STEEL PINS[1]	RELATIVE AMOUNT OF Zn REMAINING ON THE METAL SURFACE (NET COUNTS/MINUTE)
None	0
10-minute immersion in 2% Zn* DDTP in hexane at 77°F.	717 ± 10
Same followed by successive rinses in the following solvents	
Heptane (77°F)	366 ± 7
Boiling heptane	354 ± 7
Methanol (77°F)	333 ± 6
Boiling methanol	327 ± 6
Carbon disulfide	317 ± 6
Diethyl ether	303 ± 6

[1] SAE 1020, polished with 280 grit emery cloth.

TABLE 10. EFFECT OF TIME, CONCENTRATION, AND TEMPERATURE ON THE RETENTION OF ZINC BY STEEL

	RELATIVE AMOUNT OF ZINC RETAINED BY STEEL[1]			
Concentration of Zn* DDTP in White Oil, Wt. %:	0.01	0.1	1.0	
Temperature, °F	70	70	70	300
Time of Immersion (Hours)				
1	1	3	20	334
24	5	16	62	807

[1] After repeated rinsings in heptane.

It is seen in Table 10 that raising the temperature for 70°F. to 300°F. causes a 15-fold increase in the amount of zinc picked up by the steel. It therefore seems unlikely that this retention of zinc is due solely to a simple adsorption process. Some chemical reaction must be involved.

In a previous section it was shown that zinc dialkyl dithiophosphate is very effective as an antiwear agent in a variety of lubricants. However, it has been found that lubricant composition has a profound effect

on the amount of zinc pick-up by steel strips immersed in blends containing Zn DDTP. As seen in Table 11, there is no correlation between the quantity of zinc retained by the steel and valve lifter wear.

TABLE 11. ZINC RETAINED BY STEEL AND VALVE LIFTER WEAR

LUBRICANT	RELATIVE AMOUNT OF ZINC RETAINED BY STEEL[1]	RELATIVE VALVE LIFTER WEAR WITH 1.3 WT. % ZINC DIALKYL DITHIOPHOSPHATE[2]
A	100	12
B	1	7
C	2	17

[1]Immersed in 1% Zn* DDTP in white oil for 24 hours at 300°F.
[2]Derived from 4-methyl-2-pentanol.

These data indicate that the wear-reducing ability of zinc dialkyl dithiophosphate may not depend directly on the formation of protective surface films which contain zinc. It should be possible to resolve the roles being played by phosphorus and sulfur in the action of zinc dialkyl dithiophosphate by radioactively tagging these atoms and conducting similar studies of metal-surface reactions.

RESUME

In conclusion, it appears that the use of radiotracers in studying valve train wear in gasoline engines offers many advantages. With radioactive valve lifters in an engine, wear can be determined rapidly, continuously, and accurately without exaggerating the test conditions. This makes it possible to investigate more variables in a shorter period of time. In addition, the radioactive valve lifter technique permits studies which could not have been made otherwise, such as those relating to metal transfer and the detailed nature of the valve lifter wear debris. The same approach might also be extended to the use of a radioactive camshaft in an engine to study wear. Using radiotracers to "tag" certain lubricant additives should also shed light on the mechanism by which these additives function in reducing valve train wear.

BIBLIOGRAPHY

1. P. L. Pinnotti, D. E. Hull, and E. J. McLaughlin, *SAE J.*, 57, No. 6, 1949, 52.
2. H. R. Jackson, F. C. Burk, L. J. Test, and A. T. Cowell, *SAE Trans.* 6, 1952, 519.
3. H. R. Jackson, *SAE Trans.*, 61, 1953, 233.
4. H. R. Jackson and W. Schreiber, Paper, A.C.S. Sect. Meet., Philadelphia (January 29, 1953).
5. A. Dyson and K. R. Williams, Paper, Inst. Petr. Symp., London (April 22, 1953).
6. M. Popovich and R. W. Peterson, Bulletin No. 33, Oregon State College, Eng. Expt. Sta., Corvallis, Ore. (July 1953).
7. Yu. S. Zaslavskii, G. I. Shor, and F. B. Lebedwa, *Izvest. Akad. Nauk. S.S.S.R.*, Otdel. Tekh. Nauk., 1598 (1953).
8. A. Hundere, G. C. Lawrason and J. P. O'Meara, Paper, A.S.L.E. 10th Ann. Meet., Chicago (April 13-15, 1955).
9. W. R. Miller and H. R. Jackson, Paper, A.S.L.E. 10th Ann. Meet., Chicago (April 13-15, 1955).
10. P. E. D'iachenko and A. I. Nisnevich, *Vestnik Mashinostroeniia* v. 35, No. 7, July, 1955, 19-22.
11. Yu. S. Zaslavskii, *Sessiya Akad. Nauk. S.S.S.R.* po Mirnomu Ispol'zovaniyu Atomnoi Energii; Zasadaniya Otdel. Tekh. Nauk., 1955, 115-38.
12. V. N. Borsoff, D. L. Cook, and J. W. Otvos, *Nucleonics* 10, No. 10, 1952, 67-69.
13. V. N. Borsoff and F. C. Younger, Paper, A.S.L.E. 8th Ann. Meet., Boston (April 13, 1953).
14. V. N. Borsoff, Paper, A.S.L.E. 10th Ann. Meet., Chicago (March 13-15, 1955).
15. F. L. Schwartz and R. H. Eaton, *SAE Trans.*, 63, 1955, 506-14.
16. J. B. Bidwell and R. K. Williams, Paper, SAE Summer Meet., Atlantic City (June 6-11, 1954).
17. E. B. Etchells, R. F. Thomson, G. H. Robinson, and G. K. Malone, Paper, SAE Golden Anniv. Passenger Car, Body, and Materials Meet., Detroit (March 1-3, 1955).
18. Unpublished Work, Esso Research and Engineering Co.

Viscosity of Polybutenes

(*Continued from p. 301*)

3. The viscosities of polybutene blends are less sensitive to pressure and temperature changes than those of the fractionated polymers.

BIBLIOGRAPHY

1. Barr, W. E., Anhorn, V. J., and Hanson, W. E., *Instruments* V. 20, 1947, p. 342.
2. Bondi, A., "Physical Chemistry of Lubricating Oils," Reinhold, New York 1951.
3. Bridgman, P. W., "Physics of High Pressure," MacMillan, New York 1931.
4. Dow, R. B., *J. Appl. Phys.* V. 8, 1937, pp. 367–72.
5. Dow, R. B., and Fink, C. E., *J. Appl. Phys.* V. 11, 1940, pp. 353–7.
6. Flowers, A. E., *Proc. ASTM* V. 14, Pt. 2, 1914, pp. 565–616.
7. Glasstone, S., Laidler, K. J., and Eyring, H., "The Theory of Rate Processes," McGraw-Hill, New York, 1941, Chap. IX.
8. Hersey, M. D. and Shore, H., *Mech. Eng.* V. 50, 1928, pp. 221–32.
9. Menzies, A. W. C., and Wright, S. L., Jr., *J. Amer. Chem. Soc.* V. 43, 1921, p. 2314.

A Survey of Journal Bearing Literature

- Evaluated abstracts of the most important papers and books written on the subject of journal bearings. Makes your bearing design more simplified. Examples of designs and applications, installations, maintenance, and key research in this specialized area of design.
- Results of an eight-year program in journal bearing literature searching, financed by industry and written by Professor D. D. Fuller, Department of Mechanical Engineering, Columbia University, and Principal Scientist, Franklin Institute Laboratories for Research and Development. $15.00 per copy.
- For your copy simply write: ASLE, 84 E. Randolph St., Chicago 1, Ill.

Radiotracer Study of the Effect of Lubricants On Metal Transfer in Drawing Brass

C. Fisher, A. Shapiro, S. Berk, M. Petronio, L. Teitell, and H. Gisser, Frankford Arsenal, Phila., Pa.

INTRODUCTION

The work necessary to draw metals through dies consists of the work required to deform plastically the metal and the work expended in overcoming the forces of friction. Associated with the frictional forces is the observed transfer of metal from the work to the tools, which, in the light of current theory (1,2,3) probably takes place by the following mechanism. As the tools and metal slide over each other, welds are formed and broken. Consideration of relative strength of the metal indicates that metal will be transferred to the tools. Because of the work hardening characteristics of metals, the portion of the metal which is transferred to the tools will have a higher tensile strength than the metal subsequently passing over the tool. This results in further transfer of metal from subsequent draw pieces. These factors result in the build up on the tools becoming progressively larger until it reaches such dimensions that the work is scratched or torn. At this time the transferred metal may frequently be observed as a visual deposit on the tools. Under most operating conditions it is possible to minimize this effect with good lubrication but almost never is it completely eliminated.

Most investigators have been concerned with the prevention of metal build-up and consequently have directed their efforts to improve lubricants, and considerable success has been attained in the development of useful draw lubricants on a purely performance basis. This has required, however, years of experience and engineering tests.

The expanded use of new metals and alloys, and the need for rapid development of lubricants for their working, makes it desirable that the mechanism of lubrication during drawing of metals be further clarified. In addition, it is necessary to have a rapid experimental means for determining transferred metal during the drawing operation, since determination of transferred metal in a direct chemical analysis requires that several thousand pieces be drawn with a set of tools before sufficient metal is transferred. The use of radioactive tracers is appropriate for this purpose. Accordingly, a study was undertaken of the transfer of metal during the drawing operation with lubricants of various compositions, using radiotracer techniques.

Although radiotracer techniques have not been widely used to study metal drawing, they have been utilized extensively in other friction and lubrication research. Bowden and Tabor (4) have made extensive studies of metal transfer between a plate and a slider, and by radioactive means have measured quantitatively the amount of metal transferred. A number of radiotracer investigations have been made in cutting oils (5). Other lubrication problems extensively investigated are those dealing with engine wear. In this case the piston or some other engine part was made radioactive by neutron activation and the wear of the part studied by the radioactivity deposited in the lubricant (6).

RADIOACTIVITY PROCEDURES

Two procedures were considered for making the draw pieces radioactive. The first method was irradiation of pieces with neutrons from a nuclear reactor. It was calculated that each piece would require about 2 millicuries of radioactive zinc and, in order to obtain this activity, a two week irradiation period would be required. At the time this work was done the neutron flux of the Brookhaven pile was about 2.5×10^{12}. A single draw piece irradiated under these conditions was too radioactive to handle upon removal from the reactor. However, after one week the radiation was approximately 1.5 roentgens per hour. It is evident that at the end of the irradiation period the draw pieces are too radioactive to handle without expensive shielding. A few weeks storage at the irradiation site would allow the short half-life emitters, such as copper-64, to decay. However, even with the decay of the copper-64, the amount of zinc-65 present would still offer a considerable

radiation hazard. Another disadvantage of this technique is that the amount of radioactivity in the draw pieces irradiated in different locations in the reactor would vary and the amount of radioactive brass measured would not be comparable for different draw pieces.

The method chosen was to electroplate radioactive brass on the draw pieces. This could be accomplished by using copper-64 with a short half-life of 12.8 hours or zinc-65 with a comparatively long half-life of 250 days. Radio-zinc was chosen because of its reasonable half-life. Zinc-65 has a complex decay scheme emitting positrons (2.5 percent) with an energy of 0.325 Mev, gammas (45 percent) with an energy of 1.12 Mev and electron capture (97.5 percent.)

The use of radiozinc-plated brass draw pieces offered a number of advantages. First, the drawing of the radioactive pieces offered a minimum of radiation hazard (2 to 20 mr at the surface of the draw piece.) Secondly, since the radioactivity was confined to a plating thickness of 0.1 mil a small amount of metal transfer could readily be measured by the scintilation counting method.

Thirdly, electroplating gives good uniformity in the thickness of the plate, thereby eliminating the problem of radioactive variation between different draw pieces. Electrodeposited brass has metallurgical properties similar to the brass of the cartridge case. According to Blum and Hogaboom (7) yellow brass deposits containing from 20 to 38 percent of zinc (alpha brass) have the same cubic structure and lattice spacing as the cast, recrystallized brass of the same composition; and electrodeposited brass has the same X-ray structure as cast alloys of the same composition.

TRACER TECHNIQUE AND MEASUREMENT

Caliber .30 brass third draw pieces were used in all tests. The composition of the brass is:

Cu	68.5–71.5%
Pb	.07 (max)
Fe	.07 (max)
Total other than Cu and Zn	0.15
Zn remainder	(about 30)

Electroplating of Brass Pieces

The composition of the plating bath used to deposit radioactive brass on the draw pieces was:

Cuprous cyanide, CuCN (Tech.)	24.3 g
Zinc cyanide, $Zn(CN)_2$ (C.P.)	13.2 g
Sodium cyanide, NaCN (C.P.)	45.0 g
Sodium hydroxide, NaOH (C.P.)	5.0 g
Distilled water	1 liter

Prior to this plating operation the plating bath was made radioactive by the addition of 2.5 ml of zinc-65 chloride in dilute hydrochloric acid solution. The radioactive zinc solution had an activity of 5.1 millicuries and a zinc content of 5.0 milligrams. In the plating bath there were 1185 nonradioactive zinc atoms for every radioactive zinc atom.

Eight hundred milliliters of the filtered plating solution was added to a container 8 in. high and 6 in. i.d. (cut from a 90mm brass cartridge case) which served as an anode and container for the plating bath. A 14-inch brass rod mounted in the center of the brass container served as a holder and cathode for the draw pieces. A water bath was used to maintain the plating solution temperature at 40 ± 1° C. A plating time of 20 minutes was used with a current of 0.11 to 0.12 amperes for each draw piece. Current was supplied from a 4.5 ampere selenium rectifier and cathode current measured with a microammeter. The theoretical weight of brass deposited under these conditions was 47.8 mg. The actual weight varied from 42-55 mg. Plating efficiency at the cathode was better than 90 percent. The thickness of the brass plate on the draw cases was 0.0001 inch.

It was expected from the composition of the plating solution that the brass plate would have a copper to zinc ratio of about 70:30. An analysis was made of the composition of the plated brass by plating a number of caliber .30 steel draw pieces. The brass plate was stripped from the steel cases using an ammoniacal peroxide solution (equal parts of NH_4OH and 3 percent H_2O_2). The copper content of the plated brass ranged from 60 to 68 percent (32 to 40 percent zinc by difference). Each plated draw piece had a radioactivity of approximately 10 microcuries of zinc-65.

METHODS OF MEASURING RADIOACTIVITY ON DIES

Gamma scintillation counting was selected as the best method for measuring the amount of zinc-65 in the radioactive brass transferred to the dies. Sodium iodide (thallium activated) crystals were used as phosphors in the counters. Two methods were used to measure the radioactivity on the dies directly and a third method, liquid counting, for determining the radioactive brass after removal from the dies.

1. *External die counting method.* In the early stages of this investigation, the narrow mouth of the die was placed in contact with the end of a scintillation counter (1 x 1 in. NaI (Tl) crystal). The counter was shielded with a vertical lead shield.

2. *Internal die counting method.* It was found that the radioactive zinc deposited on the die could be measured more efficiently by using a smaller crystal that could be inserted into the mouth of the die. A 1 X ¼ in. NaI (Tl) crystal was mounted to the photomultiplier tube of scintillation counter. The shielded crystal was inserted into the throat of the steel die and the radioactivity of the die measured. The entire counting set up was inclosed in a vertical shield which resulted in a very low background counting rate (30 c/m).

3. *Solution counting method.* During the later phases of this work a solution counting method was

used. After each drawing operation the die was removed from the machine and the bulk of the oil base lubricants was removed by rinsing the die in toluene. The soap lubricant was removed by rinsing the die in hot water. The solvent cleaned die was then placed in a 250 ml beaker and 50 ml of brass stripping solution (equal parts of concentrated ammonium hydroxide and 3 percent hydrogen peroxide) added. After 5 minutes the die was removed, rinsed with distilled water, and the rinse water combined with stripping solutions. The radioactive brass stripping solution was concentrated on a hot plate to a 4 ml volume, cooled, and transferred to a 10 ml centrifuge tube for scintillation counting. The flask which contained the radioactive brass stripping solution was rinsed with 25 ml of distilled water, the washing concentrated by evaporation, and transferred to a second tube. The original flask was finally rinsed with 2-ml portions of 20 percent nitric acid and transferred to a third tube. The radioactivity measured from the three tubes was added and reported in terms of micrograms of brass removed. The radioactivity was measured using a NaI (Tl) gamma well crystal mounted to the photomultiplier tube in the scintillation counter. The assembled scintillation counting apparatus was mounted in a lead well shield. The counting efficiency of this set-up was 9 percent for the zinc-65 labeled brass. The last two methods (No. 2 and 3) for measuring the radioactive brass removed by the steel dies from zinc-65 labeled cartridge cases were compared. The results, using two dies and six lubricants, are given in Table 1. The well

TABLE 1. COMPARISON OF SOLUTION COUNTING AND DIE COUNTING (INTERNAL)

LUBRICANT	DIE NO.	COUNTS PER MINUTE		SOLUTION COUNT
		SOLUTION	DIE (INTERNAL)	DIE COUNT
E	D17	13,830	1560	8.90
E	E16	3,260	320	10.2
F	D17	8,860	870	10.2
D	D17	9,260	1490	6.22
G	E16	2,880	250	11.5
C	E16	3,440	300	11.5
B	E16	6,780	920	7.38

Lubricants are described in Table 4

scintillation counter for measuring the radioactive brass solution stripped from the dies was far more efficient than the method of inserting a small shield scintillation crystal directly in the throat of the die. The former method yielded about 10 times the number of counts obtained with the latter.

METAL TRANSFER IN DRAWING

All drawing operations were performed on a testing machine (Figure 1) using standard fourth draw tools, drawing at a speed of 2 inches per minute. The draw pieces, both radioactive and inactive, were drawn through new steel dies having a Rockwell hardness of

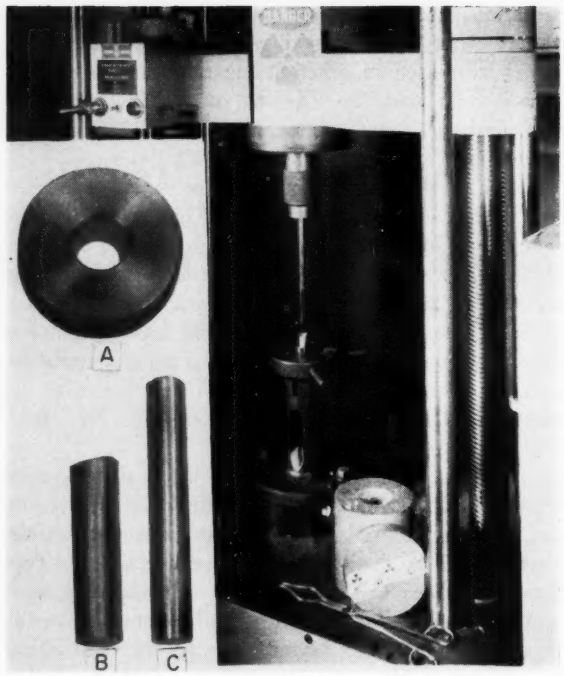


Figure 1. Setup for drawing operation. A. Die B. Third draw piece C. Fourth draw piece.

C63-65. Except as otherwise indicated, the draw pieces were dipped in the lubricant, allowed to drain for one hour, then redipped in the lubricant and immediately drawn.

Preliminary experimental work on metal transfer was done using soap solution as a lubricant. The draw pieces were lubricated by immersing in 2 percent aqueous solution of beef tallow sodium soap and were immediately drawn without drying. A radioactive brass draw piece was drawn first and the radioactivity transferred to the die measured by placing the die in contact with the shielded NaI(Tl) crystal of a scintillation counter (external die counting method) inclosed in a lead shield. An inactive brass draw piece was then drawn through the die and the radioactivity that remained on the die was measured. This procedure was followed for seven radioactive and seven inactive draw pieces. The results shown in Table 2 give the amounts of brass removed from the draw pieces and deposited onto the die. In all cases the die had increased radioactivity after a radioactive piece was drawn. It is evident that in each drawing operation that brass is removed from the die in addition to the deposition of fresh brass. In other words there is an interchange of brass between the work piece and the brass deposited on the die in previous draws. This interchange is not explained by current theories of metal transfer and it must be concluded that present explanations of the mechanism of metal transfer represent an oversimplification of the actual process.

It was of interest to determine the total amount of brass remaining on a die after production use. A production die, which had a visible ring of brass on its

TABLE 2. Radioactivity Deposited and Removed from the Die in Alternate Drawing of Radioactive and Inactive Drawpieces[a]

Order of Draw	Net Counts per Minute above Background[b]	Change from Previous Piece	Percent Brass Removed from Die by Drawing Inactive Case
Active	172		
Inactive	35	−137	80
Active	98	+63	
Inactive	28	−70	71
Active	137	+109	
Inactive	25	−122	82
Active	106	+81	
Inactive	40	−66	62
Active	870	+830	
Inactive	208	−662	76
Active	353	+145	
Inactive	142	−211	60
Active	214	+72	
Inactive	105	−109	51

[a]2% Beef tallow soap lubricant
[b]One count per minute is equivalent to 0.3 microgram brass

TABLE 3. Effect of Oxide Film and Air Drying of Soap Films on Metal Interchange

Die No.	Lubricant	Counts per Minute in Die: Deposited by Zn-65 Labeled Piece	Counts per Minute in Die: Residual Activity after Drawing Inactive Piece	Activity Removed %
B-2	2% beef tallow soap, without air drying	8940	1840	79
B-3	2% beef tallow soap, without air drying	2894	531	82
B-1	2% beef tallow soap, with a two hour air dry	1100	115	89
B-4	2% sodium stearate with a two hour air dry	3071	311	90
B-5	Oxide film on plated case boiling in water for one hour	3039	506	83

land, and through which 24,000 pieces had been drawn, was analyzed by wet methods for copper. Results show that the total brass on the die contained approximately 1,000 micrograms of copper. The net amount of brass transferred per piece drawn is approximately 0.06 microgram. The experimental evidence from the tracer technique indicates that the transfer of brass to the die (as opposed to the net transfer) is from 20 to 250 micrograms of brass. It follows, therefore, that the amount of brass exchanged between die and draw piece is very large compared to the net amount transferred to the die.

It had been observed that, in using a new die, the first piece drawn gave much higher draw forces than subsequent pieces. In order to eliminate this variable, at least one inactive piece was drawn through each new die prior to drawing the radioactive pieces.

Experiments were conducted to determine whether the amount of brass transferred to the die and the amount removed from the die are affected by factors such as air drying of the soap solution and an oxide film on the surface of the piece. Five dies were used and two nonradioactive pieces were drawn through each die for conditioning before drawing a radioactive piece.

The amount of radioactivity transferred to the die was measured by the "external die counting" method. An inactive case was then drawn and the amount of radioactivity removed from the die was determined. The data obtained are shown in Table 3. Any differences caused by air drying of the lubricant cannot be discerned. Only one active piece was drawn through each die, and there is a large difference in the amounts of brass transferred by the two drawings using wet soap as the lubricant. This experiment gives additional evidence that in drawing brass pieces, even with variations in the lubricant, a high percentage (79-90 percent) of the activity transferred from a radioactive piece is removed by a subsequently drawn inactive piece.

It was also observed that in drawing an oxide coated draw piece, produced by boiling in water for one hour, there was no increase in radioactivity over that observed with the soap solutions. Spring and Gisser (8) have previously reported that the oxide film normally present on brass draw pieces aids in lubrication.

EFFECT OF LUBRICANTS ON METAL TRANSFER

Metal transfer was measured in drawing experiments with seven lubricants selected for variability in composition. The lubricants are described in Table 4. These compositions are commonly used in metal drawing operations but are not generally used for drawing brass. The sulfurized lubricants are seldom used in working copper or copper bearing alloys because of their strong tendency to stain or blacken. Sulfurized lubricants are used only when severe drawing conditions prevail. Chlorinated oils, like the sulfurized oils, provide extreme pressure characteristics and they are used when metal reduction is severe. Fatty oils are used extensively in deep drawing operations; the most commonly used material is lard oil. Fatty oils are used to reduce friction and their performance is governed to a considerable extent by the amount and type of free fatty acids present. Sulfurized fatty oils possess the combined properties of extreme pressure characteristics and friction reduction.

The data in Table 4 show that the sulfurized lard oil, and sulfurized mineral oil resulted in the least transfer of brass to the dies. Lard oil and oleic acid

TABLE 4. AMOUNTS OF BRASS DEPOSITED ON DIES AFTER DRAWING RADIOACTIVE BRASS PIECES

LUBRICANT	MICROGRAMS OF BRASS DEPOSITED ON DIE[a]					
	C-14	C-9	E-16	D-17	AVERAGE OF 4 DIES	AVERAGE OF 3 DIES (D-17 OMITTED)
A. 2% Beef tallow soda soap in water	47	23	89	251	102	53
B. 5% Chlorinated paraffin (40–42% Cl) in mineral oil[b]	29	19	81	436	141	43
C. 10% Sulfurized lard oil (MIL-O-16247) in mineral oil[b]	9	14	41	60	31	21
D. 10% Lard oil (C-O-376A) in mineral oil[b]	20	24	54	111	52	33
E. 10% Oleic acid (U.S.P.) in mineral oil[b]	20	23	39	166	62	27
F. Mineral oil[b]	66	68	110	106	88	81
G. Sulfurized mineral oil (0.8–1.1% S)	10	18	35	34	24	21

[a]Each μg of brass is equivalent to 83.3 c/m of radioactive zinc measured by solution counting
[b]Military Symbol 3050

resulted in an intermediate amount of brass transfer, while the chlorinated oil, the soap, and plain mineral oil resulted in the largest amount of brass transfer. The mineral oil without additives resulted in approximately four times as much brass transferred to the dies as the lubricants which resulted in the least metal transfer. The order in which the lubricants were used varied from die to die. This order was found to have had no significant effect on the results. There exists wide variation in the count for any one lubricant in each of the four dies. From this it appears as though the dies may be responsible for this variation. It is evident from the data that one of the four dies, D-17, gave values much higher than the other three dies. Therefore, in Table 4 the average amount of brass deposited is calculated for all four dies and for only the three dies that gave fairly consistent values. (The dies had a land diameter of 0.4670 ± 0.0001″ and the entrance angles were 12° ± 10′). The data in Table 4 were statistically analyzed (9) in order to determine which experimental variables were of significance with respect to the results obtained. The F ratio showed that both the dies and the lubricants were significant at the 0.5 percent level with respect to the observed differences in metal transfer.

The metal transfer data obtained may be explained by examining the possible reactions between metal and the lubricants. The low metal transfer obtained with the sulfurized oils is attributed to the reactivity of the sulfur in the oils. The sulfurized mineral oil contains highly reactive sulfur as evidenced by the rapid attack on a polished copper strip in the heated oil. The sulfurized lard oil is less reactive than the sulfurized mineral oil as evidenced by a lower level of activity in copper strip test. Nevertheless, a sulfide film is formed on the metal surface in either oil and it is the sulfide film which is associated with the decrease in metal transfer.

Oleic acid is also quite reactive with copper and zinc to form copper and zinc oleates. It has been shown (10) that under sliding conditions, hot spots of 500 to 600° C frequently occur and there is some evidence for the occurrence of occasional hot spots which are considerably higher in temperature. Since these temperatures are well above the melting points of the copper and zinc oleates, the latter would not be expected to give results as good as the sulfides.

The action of lard oil in lubrication is not completely understood, but some of its effects are due to its free fatty acid content. Bowden (11) has shown that esters of fatty acids are effective lubricants, within limitations, but not quite as effective as the fatty acids themselves. He has indicated that the effectiveness of esters is due to possible hydrolysis to liberate fatty acids. There is a likelihood that similar conditions prevail in the case of the lard oil.

Chlorinated compounds form copper and zinc chlorides and are slower acting that the sulfurized compounds (12). Thus, the poorer performance of the chlorine compounds can be explained on this basis, and on the fact that the chlorides have considerably lower melting points than the sulphides. Thus they afford less protection against metal transfer.

Beef tallow soap, as shown by Spring (13) owes its action to hydrolysis and the formation of acid soap (a normal constituent of soap dispersions (14)). In this instance time must elapse for hydrolysis to proceed and then, for reaction to occur. This process probably takes longer than the reaction with fatty acids. Soap, therefore, would be expected to give poorer results than the fatty acids. Support is given to this hypothesis by data of Spring (13) who has shown that the use of dry films of fatty acids decreases the primary maximum draw force to almost that obtained on prolonged immersion in a dilute soap solution. Reaction time is of definite importance.

Mineral oil, which contains no chemically active constituents and which is therefore incapable of reaction with a metal surface, should exhibit the poorest metal transfer properties.

A plot of the draw force vs length of draw has a characteristically high peak shortly after the beginning of the draw. This peak occurs because the amount of metal being deformed is greater at the start of the draw than during the ironing which occurs along the side walls of the draw piece. Figure 2 shows the rela-

tionship between the amount of brass transferred and the magnitude of the peak force. This figure shows that the peak draw force and amount of brass transferred to the die are related, and that this relationship does not depend on the lubricant under the conditions of the experimental work described here. Since both the energy expended in drawing the amount of metal transferred to the tools are measures of the efficiency of lubrication, measurements of metal transfer may be useful in lubricant evaluation in the drawing operation.

SUMMARY

A study was made of the effect of lubricants on metal transfer in a drawing operation using radioactive tracer techniques. The experimental system consisted of drawing a caliber .30 brass draw piece plated with brass containing zinc-65 and measuring the radioactivity transferred to the die. Results showed that there is a continual interchange of brass between the die and the work and that the amount of brass transferred is related to the draw forces. Sulfurized lard oil and sulfurized mineral oil resulted in the least metal transfer to the dies. Lard oil and oleic acid resulted in an intermediate amount of transfer, while chlorinated oil, soap and straight mineral oil resulted in the largest amount of metal transfer. The radioactive tracer technique may be used to study metal transfer and to evaluate lubricants in the drawing operation.

REFERENCES

1. Rabinowicz, E. and Tabor, D., *Proc. Roy. Soc.*, A. 208, 1951, 455.
2. Ibid, *Brit. J. Appl. Phys.* Suppl. No. 1, 1951, 82.
3. Kerridge, M., *Proc. Phys. Soc.*, B. 68, 1955, 400.
4. Bowden, F. P. and Tabor, D., "The Friction and Lubrication of Solids," Oxford University Press, London 1950, p. 82.
5. Merchant, M. E., *Trans. Amer. Soc. Mech. Eng.* 75, No. 5, 1953, 549.
6. Merchant, M. E., Ernst, H. and Krabacher, E. J. *Nucleonics*, 14, 1956, 54.

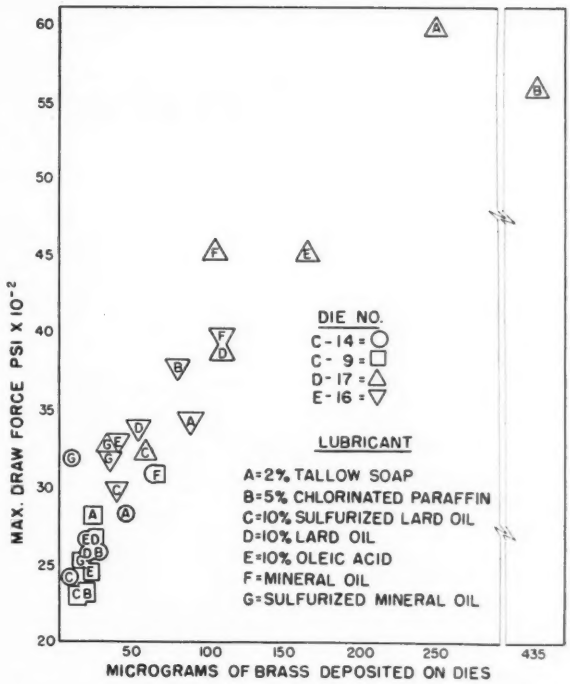


Figure 2. Relationship between peak draw force and amount of brass transferred to the dies.

7. Blum, W., and Hogaboom, G. B., "Principles of Electroplating and Electroforming," McGraw-Hill Book Co., New York, 1949, p. 403.
8. Spring, S. and Gisser, H., *"Lubricants for Drawing Brass Cartridge Cases,"* Frankford Arsenal, R-63B, March 1942.
9. Brownlee, K. A., "Industrial Experimentation" Chemical Publishing Co., London, 1953, p. 51.
10. Bowden, F. P. and Tabor, D., "The Friction and Lubrication of Solids," Oxford University Press, London, 1950, p. 50.
11. Ibid, p. 215.
12. Prutton, C. F., Turnbull, D., and Dlouhy, G., *J. Inst. Petroleum*, 32, 1946, 90.
13. Spring, S., *Steel*, 117, No. 8, 20 Aug. 1945, 135.
14. Powney, J. and Jordon, D. O., *Trans. Faraday Soc.*, 34, 1938, 363.

mbi
ON GUARD SINCE 1888

LUBRICATING GREASES
METAL WORKING LUBRICANTS
SPECIAL PROCESS OILS

"Never Underestimate the Importance of Lubrication"

Consult Our Lubrication Engineers

MAGIE BROTHERS OIL COMPANY
FRANKLIN PARK, ILLINOIS
CHICAGO PHONE: TUXEDO 9-4800

Product Literature

NEW DIEPOXIDES DESCRIBED

Technical information, including properties and suggested uses, of two new diepoxides is available in two bulletins just published.

New diepoxides are dicyclopentadiene dioxide, described in bulletin 95, and limonene dioxide, described in bulletin 96.

The new diepoxides, which combine the reactivity of the epoxy group with their bifunctional nature, are expected to find their principal use as constituents in epoxy and other resin systems where they can function as diluents, crosslinking agents, or modifiers of resin properties.

Applications for the diepoxides are as intermediates in the preparation of protective coatings, plasticizers, lubricants and lubricant additives, and in organic synthesis.

Copies of bulletins 95 and 96 and samples of these new chemicals may be obtained free on request from Becco Chemical Div., Food Machinery and Chemical Corporation, Station B, Buffalo 7, N. Y.

HYDRAULIC PUMPS AND FLUID MOTORS

Catalog No. 111 describes oil hydraulic pumps available with capacities from 1.2 to 14.2 gpm; for continuous service pressure to 1500 psi; speeds to 3600 rpm. Complete information includes construction features, performance curves, pump-motor combinations, duplex or tandem models, and geared flow dividers.

For your copy, write Department PR, Tuthill Pump Co., 971 E. 95th Street, Chicago 19, Ill.

BACTERIOSTATIC BONDING AGENT

Aliphatic chemicals which function as bacteriostats, flexible hardeners in epoxy resins, anti-stripping agents in asphalts, and corrosion inhibitors and fuel additives in petroleum products is described in a booklet called Duomeens. The duomeens are an alkyl group of trimethylene diamines derived from coco, soya, oleic and tallow fatty acids. They are cationic surface active agents which will bond strongly to metal, textiles, plastics, and other surfaces. The booklet covers the chemical and physical properties of the duomeens and their salts, general reactions and applications. Booklet is available from Armour & Co., Chemical Division, 1355 W. 31st Street, Chicago 9, Ill.

WELDED SLEEVE-BEARING ALLOYS

Welded hard-faced alloys to increase the service life of critical surfaces in sleeve-type bearings is described in a data sheet just released. Excellent resistance to high temperatures, corrosive acids, and other oxidizing media can be obtained from these bearings, custom produced in stainless steel and ferrous alloys to specification. Reduced wear or galling failures are claimed. Copies of the free data sheet are available from Cleveland Hard Facing, Inc., 3047 Stillson Avenue, Cleveland 5, Ohio.

WIRE ROPE CARE AND USES

Illustrated handbook on selection, use and care of wire rope is now available to users, buyers and sellers of wire rope. Explained in the thirty-six page book are methods of socketing, splicing, installation, and important points on safety. Free copies are available from Wire Rope Corp. of America, 609 No. Second St., St. Joseph, Mo.

PRECISION MEASURING VALVE SYSTEMS

Readily adapted to automated systems, new booklet describes advantages of precision valve and their design application to problems in dispensing measured quantities of fluid and semi-fluid materials. Applications include filling gear cases, small transmissions, and machine bearings. Systems may be permanent or portable, and will dispense as little as 1/20 ounce or more than two quarts per application. For complete information on Lincoln Engineering Precision Measuring Valve Systems write for bulletin No. 682, Lincoln Engineering Co., 5743 Natural Bridge Ave., St. Louis 20, Mo.

SOLID FILM LUBRICANT APPLICATIONS

Catalog just released describes first "family" of solid film lubricants formulated to solve lubricant problems which arise under conditions of high temperature (to 1500° F), low temperature (−300° F), corrosion resistance, high loading (225,000 psi), and high speeds (to 30,000 rpm.) Coatings described can be applied and bonded to the surface of all metals and their derivative alloys including stainless steel, aluminum, and titanium. Data is included in catalog No. LB-6-1157 available from Electrofilm, Inc., P. O. Box 106, North Hollywood, Calif.

HYDRAULIC PISTON PUMP CUPS

Latest types of molded cups for pump pistons, hydraulic service, and for pneumatic equipment is described in new bulletin covering synthetic rubber, leather, reinforced synthetic rubber, metal bonded and metal reinforced materials. Tables illustrate the most popular cups and detail recommended services on a variety of general applications. Bulletin AD-145 is available from The Garlock Packing Co., 423 Main St., Palmyra, N. Y.

MACHINE TOOL MIST COOLANT SYSTEM

Four-page bulletin describes how mist coolant unit improves cooling efficiency and work finish and increases tool life in boring, grinding, milling, tapping, sawing, and turning operations. Included in bulletin is method of branching from existing lines to eliminate siphon lift problems. Spraymist Bulletin F-7 may be obtained from Bijur Lubricating Corp., 151 W. Passaic St., Rochelle Park, N. J.

SPECIFICATION LUBRICANT LIST

References on 250 specifications and MIL equivalents for approximately 140 old aeronautical (AN-), Air Force, Army, and Navy specifications in the fields of lubricants, Hydraulics, corrosion prevention and related areas. Government Specification Product List is available from the Bray Oil Co., 3344 Medford St., Los Angeles 63, Calif.

HIGH PRESSURE HYDRAULIC HOSE AND FITTINGS

Wire braided hose and reusable fittings, including stainless steel braided hose for non-magnetic service and perforated cover hose for coal shooting, are covered in catalog 4430. Hose assemblies are cataloged and make-up instructions included. Catalog is available from Parker Fittings & Hose Div., Parker-Hannifin Corp., 17325 Euclid Ave., Cleveland 12, Ohio.

(*Continued from p. 289*)

ASME-ASLE Lubrication Conference

Plans for the fifth annual conference are progressing satisfactorily. To date, 43 papers have been offered. Extensive effort on publicity is being scheduled for the conference. A brochure was supplied at the annual meeting and also will be mailed to all past registrants. Emphasis will be placed on an appeal to the potential registrant to make the conference a part of his vacation plans. Several activities are planned for wives attending the conference with husbands as a part of the vacation-meeting appeal.

The board authorized the expenditure of $250 to establish a fund to cover expenses incurred by the committee in meeting preparation. The fund would be administered by the Executive Secretary (58-29).

Establishment of the foregoing fund as a bank account in the name of the committee, by revision to the conference regulations was approved by the board (58-30).

Projects

No report

Journal Bearing Research

Since publication of "A Survey of Journal Bearing Literature," there has been no further work by the committee. No report anticipated.

Awards

The board's action of March 3, 1953, pertaining to awards was rescinded (58-31). The awards committee were instructed to revise the specifications for the Capt. Alfred E. Hunt Memorial Award to permit its presentation to papers authored jointly by more than a single author meeting all other requirements, should a jointly authored paper be suitable for award consideration by the committee (58-32).

Education

A report of the educational course held in conjunction with the annual meeting was received.

Annual Meeting

All committee work to date indicated the success of the 1958 annual meeting.

Exhibit Arrangements

Twenty-nine of the 37 available booth spaces were sold. Unsold booths represent a loss of $2,690 in revenue anticipated by the Society. For the 1959 exhibit there will be booth space available for 50 exhibits. Plans have already been made with the Buffalo Section to stress the promotion of the 1959 exhibit at the Hotel Statler.

Annual Meeting Sites

Based upon the report of the sites committee, it was recommended that the 1962 annual meeting be held in St. Louis. To avoid conflicts with the Association of Iron & Steel Engineers' meeting, the committee recommends changing the date of the annual meeting to May. The board voted to hold the 1962 meeting in St. Louis (58-41).

Abstracts

During 1957, 68 abstracts were published in the journal. An increasing number of abstracts are now being published and more of the technical committees are contributing to the journal through this activity.

National Program

The 1958 program had 61 papers divided into 18 technical sessions. In addition, five sessions treating the education course were held concurrently. L. E. Hoyer has been appointed chairman for the 1959 program and A. B. Lindert will be vice chairman. One additional member must be appointed. K. M. Holley is chairman of the Speaker's Bureau. The national office was instructed to prepare preprints of the papers for the 1959 annual meeting and to make these available by mail order at 50¢ each (58-42).

Editorial Review

The committee is currently being reorganized. At this time it consists of the following members: John Boyd, Chairman; E. E. Bisson, W. E. Campbell, John Givens, R. K. Gould, H. W. McCulloch, Jr., A. A. Raimondi, Ernest Rabinowicz, M. C. Shaw, and L. B. Sargent, Jr.

ASLE MEMBERSHIP CLASSIFICATIONS

Membership in the American Society of Lubrication Engineers is in several grades as defined below. Assignment to grade is made by the Admissions Committee or Board of Directors on the basis of information submitted by the applicant.

Members: Members shall be persons not less than 24 years of age who: (1) are engaged in research and instruction at technical schools, universities, and various publicly and privately supported institutions in the field of lubrication; or (2) have occupied recognized positions as lubrication engineers for a period of three or more (not necessarily consecutive) years prior to date of admission, involving the responsibility for or supervision of the development, selection, field use and application of lubricants as differentiated from other activities; or (3) are indirectly concerned with the field of lubrication, but possessing other qualifications of experience, knowledge, and accomplishment, and have manifested a particular interest in the purposes and welfare of the Society to the extent that their membership would be a valuable contribution to the successful functioning of its activities. Fee $15.00.

Associate Members: Associate Members shall be persons less than 24 years of age, and those who do not completely fulfill the membership requirements for Members. Fee $7.50.

Sectional Sustaining Members: are such persons or organizations as may be interested in and desire to contribute to the support of the purposes and activities of a local Section of the Society. Fee $25.00.

Industrial Members: Industrial Members are such persons or organizations as may be interested in and desire to contribute to supporting the purposes and activities of the Society. Fee $150.00.

For application blanks or further information, write:

ASLE

84 E. Randolph St.
Chicago 1, Ill.

ASLE Publications

Interpreting Service Damage In Rolling Type Bearings

A manual on ball and roller bearing damage which includes drawings, tables, and 74 photographs for aiding in the classification and identification of the causes of many of the common types of bearing damage. $1.00 per copy, $2.00 Foreign.

Lubrication Engineering Decennial Index

Subject & Author Indexes listing the papers published in **"Lubrication Engineering,"** Journal of the American Society of Lubrication Engineers, in Volumes 1 thru 10 (1945 thru 1954). 50¢ per copy, $1.00 Foreign.

Petroleum-Type Hydraulic Fluids

Second in the series of ASLE monographs, covering Hydraulic Oil Specifications & Service Properties, Viscosity, Viscosity Index, Demulsibility, Oxidation Stability, Lubricating Value, Rust & Corrosion Preventive Qualities. $1.00 per copy, $2.00 Foreign.

Physical Properties Of Lubricants

First in the series of ASLE monographs, covering Viscosity, Density & Specific Gravity, Cloud & Pour Points, Flash & Fire Points, Carbon Residue, Neutralization Number & Interfacial Tension, Saponification Number, Emulsification, Specific Heat. $1.00 per copy, $2.00 Foreign.

Industrial Dermatoses—Protection, Prevention, and Treatment

Eight experts in the field of industrial dermatitis assemble for the first time their experience and investigations in an ASLE-sponsored effort to curb these costly diseases. The experts examine the use and handling of cutting oils, lubricants, and solvents. Protective measures such as ointments, housekeeping, and preventing bacterial decomposition are discussed. $1.00 per copy, $2.00 Foreign.

A Survey of Journal Bearing Literature

By Professor D. D. Fuller, Columbia Univ.

The results of an eight-year cooperative journal bearing research project sponsored by the ASLE and financed by industry. Over 2500 literature references have been screened and evaluated. The resulting summaries of the original articles and books includes all the pertinent information to support the 33 chapters dealing with bearing design, manufacture, and effective use of journal bearings. $15.00 per copy.

Write:

American Society of Lubrication Engineers
84 E. Randolph St. Chicago 1, Ill.

An author's guide has been revised by the committee and publication is recommended for quantity release to ASLE authors.

PUBLICATIONS

First issue of the new *ASLE Transactions* was exhibited at the annual meeting. It contains 27 papers totaling 240 pages. The committee recommends making the publication available to authors at no cost and to the membership at a moderate fee. By board action, the first issue of the bi-yearly publication will be made available to the first 750 members requesting it at $3.00 per copy, or $5.00 for the first two issues. Promotion funds of $5.00 were alloted for promotion of the new publication (58-26, 27).

With release of the July issue of the journal, *Lubrication Engineering* will be printed at the Wm. Byrd Press of Richmond, Va. Publication at the new facility will permit more economical printing of the difficult manuscripts published by the Society.

A style guide for the journal is in preparation. Its use will prevent fluctuations in publication quality.

MEMBERSHIP AND ADMISSIONS

Membership as of April 1, 1958 was 3,178, an increase of 350 members during the year. A serious number of delinquents still exists, last count showing 679 (March). Activities for 1959 will stress sectional sustaining membership.

NEW SECTIONS

Two new Sections have been chartered since April 1957. Dallas-Ft. Worth, Texas has been reported. Richmond, Va. was organized in April and was presented with their charter at the annual meeting (58-42).

INDUSTRIAL MEMBERSHIP

Three industrial memberships were lost during the past year.

HANDBOOK ADVISORY

Recent meeting of the committee has resulted in an estimated release of the handbook to the public in three years. A number of authors have been contacted; many are willing to submit material for the book.

Patent Abstracts

Compiled by Ann Burchick

Aluminum Co. of America

Production of Lubricating Oils, Patent 2,787,582 (C. H. Watkins and A. J. de Rosset, assignors to Universal Oil Products Co.) The method for producing lubricating oil which comprises separating a petroleum material into at least a light lubricating oil fraction having an end boiling above about 600 F. and a bottoms fraction having an end boiling point above about 900 F., passing at least a portion of said bottoms fraction into contact with a catalyst comprising a component containing metal from the left hand column of group VI and an iron group metal component at a temperature of from about 750 F. to about 850 F. and a hydrogen pressure in excess of about 100 psi, separating the resultant converted material into a synthetic light lubricating oil fraction and a synthetic bottoms fraction, commingling the resultant synthetic light lubricating oil fraction with the first-mentioned light lubricating oil fraction and passing the resultant mixture with hydrogen into contact with a hydrogenating catalyst at a temperature of from about 100 to about 500 F., and dewaxing the resultant hydrogenated light lubricating oil fraction to produce the aforesaid lubricating oil.

Spinning Oil Composition, Patent 2,787,594 (D. Stewart, assignor to Scottish Oils Ltd.) A composition suitable for use as a spinning oil consisting essentially of in combination the following ingredients by percent weight:

A sodium alkyl sulphate in the form of an aqueous solution and having a concentration equivalent to a 20% solution, said sulphate obtained by reacting a shale oil fraction having a boiling point within the range of 200-350 C. with sulphuric acid of 90-98% strength at a temperature under 20 C. followed by a neutralization of resulting alkyl hydrogen sulphide by treatment with a sodium base 20-40

Petroleum spindle oil fraction ...30-70

Olein 5-50

A material solubilizing agent therefor being sodium sulphate ..up to about 5

Together with an oxygen-containing organic solvent selected from the group consisting of diethylene glycol butyl ether, normal butyl alcohol, and mixtures thereof 1-10

Process for the Preparation of Synthetic Lubricants, Patent 2,787,644 (D. L. Cottle and D. W. Young, assignors to Esso Research & Engineering Co.) A new process for the preparation of compositions of matter in the lubricating oil range which comprises the steps of reacting an olefin polymer with carbon monoxide and hydrogen in the presence of a cobalt catalyst at temperatures in the range of from 200 to 400 F. and at pressures within the range of from 100 to 300 atmospheres to obtain a mixture of products, acidifying said mixture of products, raising the temperature of said acidified mixture to about 175 to about 300 F. for from one half to about 6 hours, distilling said heated mixture to recover therefrom the acetal component thereof, reacting said acetal component with formaldehyde at a temperature of about room temperature to about 500 F. for from 15 minutes to 10 hours, and separating and purifying the formal thus obtained.

White Oil Process, Patent 2,788,310 (W. A. Wilson and T. O. Wehrle, assignors to Esso Research & Engineering Co.) In a process of preparing a white oil wherein a mineral oil is initially treated to form, neutralize, and remove sulfonic acids, the improvement in final purification of the neutralized oil from which sulfonic acids have been removed, of first admixing with said oil a relatively small amount of water and then treating the resulting oil-water mixture with an amount of sulfur trioxide which, if mixed with the small amount of water alone, would form an acid having a treating strength of 60 to 80 wt. percent of free SO_3.

Extreme Pressure Lubricant, Patent 2,788,326 (A. A. Bondi and G. L. Perry, assignors to Shell Development Co.) A lubricating composition comprising a major amount of a mineral lubricating oil having incorporated therein from about a fraction of 1 to 10% of tartaric acid and from 2 to 20% of a mixture of sorbitan monooleate and polyoxyethylene sorbitan monooleate, each of said additives of said mixture being present in substantial amounts.

Traction Motor Gear Lubricant, Patent 2,789,091 (F. T. Crookshank, W. E. Jordan, G. S. Bright, and R. F. Nelson, assignors to The Texas Co.) A gear lubricant comprising 1 to 5 percent alkali metal soap, 1 to 5 percent residual oil and more than 90 percent of an oxidate obtained by air oxidation of dewaxed, deasphalted paraffin base residuum, said oxidate having a Neut. No. of 0.8 to 3 and a Sap. No. of 15 to 30 and an sus viscosity at 210 F. of 950 to 1350.

Detergent Lubricating Oils, Patent 2,789,092 (T. L. Cantrell, J. G. Peters and H. G. Smith, assignors to Gulf Oil Corp.) A lubricant composition comprising a major amount of a mineral lubricating oil and a minor amount, sufficient to confer detergency properties on the composition, of an alkaline earth metal salt of a condensation product, of 6 mols of a monoalkylated monohydric phenol having at least 4 carbon atoms in the alkyl group, 1 to 2 mols of ammonium hydroxide, 1 to 2 mols of carbon disulfide and 8 mols of formaldehyde.

Lubricating Composition, Patent 2,789,950 (R. I. Gottshall, J. G. Peters, and H. W. Swain, assignors to Gulf Oil Corp.) An improved lubricating composition consisting essentially of a major proportion of a mineral lubricating oil and minor proportions consisting of about 0.1 to about 5.0 percent by weight of an alkyl phenol, said alkyl phenol containing at least one alkyl group containing between 3 and 12 carbon atoms, about 0.001 to about 1.0 percent by weight of a substantially neutral addition product of 3-methylbutyl, 2-ethylhexyl acid orthophosphate and a primary fatty amine, said amine being a mono-alkyl amine containing from 8 to 18 carbon atoms, and an acid ester of (1) a dimeric acid derived from an unsaturated fatty acid containing from 6 to 22 carbon atoms and having from 2 to 3 ethylenic linkages per molecule and (2) a partial ester of a fatty acid containing from 12 to 24 carbon atoms and an alkitol anhydride, said acid ester containing at least one unreacted carboxyl group per molecule and wherein said acid ester is present in an amount sufficient to improve the film tenacity characteristic of the composition.

Compounded Turbine Oils, Patent 2,789,951 (R. T. Kern, Jr. and J. G. Peters, assignors to Gulf Oil Corp.) An improved turbine oil consisting essentially of a major proportion of a mineral lubricating oil and minor proportions consisting of about 0.1 to about 2.0 percent by weight of an alkyl phenol, said alkyl phenol containing at least one alkyl group containing between 3 and 12 carbon atoms, about 0.01 to about 0.1 percent by weight of a metal alkyl thiophosphate, said alkyl group containing between 3 and 12 carbon atoms, about 0.005 to about 0.2 percent by weight of a substantially neutral addition product of 3-methylbutyl, 2-ethylhexyl acid orthophosphate and a primary fatty amine, said amine being a mono-alkyl amine containing from 8 to 18 carbon atoms, and about 0.005 to about 0.8 percent by weight of an acid ester of (1) a imeric acid derived from an unsaturated fatty acid containing from 6 to 22 carbon atoms and having from 2 to 3 ethylenic linkages per molecule and (2) a partial

ester of a fatty acid containing from 12 to 24 carbon atoms and an alkitol anhydride, said acid ester containing at least one unreacted carboxyl group per molecule.

Compounded Turbine Oil, Patent 2,789,952 (T. L. Cantrell and J. G. Peters, assignors to Gulf Oil Corp.) A rust-inhibiting oil consisting essentially of a major proportion of a mineral lubricating oil and minor proportions consisting of about 0.1 to about 2.0 percent by weight of 2,6-di-tertiary-butyl-4-methylphenol, about 0.01 to about 0.1 percent by weight of zinc dihexyl thiophosphate and about 0.01 to about 1.0 percent by weight of the coco-amine salt of 3-methylbutyl, 2-ethylhexyl acid orthophosphate.

Mixed Metal Complex Salts of Phosphoric Acid Esters and Mineral Oil Compositions Containing the Same, Patent 2,790,765 (F. P. Otto and E. W. Flynn, assignors to Socony Mobil Oil Co., Inc.) A mineral lubricating oil containing a minor proportion, sufficient to improve the detergent character thereof, of a mixed-metal, zinc-containing complex salt of a partial ester of phosphoric acid having a metal content greater than that which would be equivalent to the acid-hydrogen content of said partial ester prepared by the steps of (1) reacting one mol of phosphorus pentoxide with from about one to about three mols of an organic hydroxy compound selected from the group consisting of a hydroxy-aromatic compound that has an alkyl substituent having at least 8 carbon atoms in place of a nuclear hydrogen atom thereof and a primary, aliphatic alcohol having at least 8 carbon atoms per molecule, to form an acidic, partial ester of phosphoric acid, (2) reacting said acidic, partial ester of phosphoric acid with a zinc salt reagent in an amount sufficient to furnish at least one equivalent of zinc per equivalent of acid-hydrogen content in said acidic, partial ester of phosphoric acid, and (3) reacting the product obtained in step 2 with a metal hydroxide selected from the group consisting of calcium hydroxide, barium hydroxide, strontium hydroxide, cadmium hydroxide, magnesium hydroxide and cobalt hydroxide, in an amount sufficient to furnish at least one equivalent of metal per equivalent of acid-hydrogen content in said acidic, partial ester of phosphoric acid.

Complex Metal Salts of Phosphoric Acid Esters and Mineral Oil Compositions Containing the Same, Patent 2,790,766 (F. P. Otto, assignor to Socony Mobil Oil Co., Inc.) A mineral lubricating oil containing a minor proportion, sufficient to improve the detergent character of said oil, of a complex metal salt of a partial ester of phosphoric acid having a metal content greater than that which would be equivalent to the acid-hydrogen content of said partial ester, prepared by the steps of (1) reacting one mol of phosphorus pentoxide with from about one to about three mols of an organic hydroxy aromatic compound that has an alkyl substituent having at least 8 carbon atoms in place of a nuclear hydrogen atom thereof and a primary, aliphatic alcohol having at least 8 carbon atoms per molecule, to form an acidic, partial ester of phosphoric acid, and (2) reacting said acidic, partial ester of phosphoric acid with a metal salt reagent, the metal constituent of which is selected from the group consisting of zinc, cadmium, magnesium, cobalt, barium, calcium and strontium, in an amount sufficient to furnish at least about two equivalents of metal per equivalent of acid-hydrogen content in said acidic, partial ester of phosphoric acid, and in which at least about one of said equivalents of metal is furnished by a metal carboxylate selected from the group consisting of metal acetates and metal caproates.

Grease Compositions Containing Complex Alkaline Earth Metal Salts, Patent 2,790,767 (J. J. Giammaria, assignor to Socony Mobil Oil Co., Inc.) A grease comprising an oleaginous lubricant and a gelling agent in an amount sufficient to thicken said vehicle to form a grease, said gelling agent being prepared by the steps of: (1) reacting one molar proportion of phosphorus pentoxide with from about one to about three molar proportions of an alkyl hydroxyaromatic compound of the general formula $R—A(OH)_n$ wherein R is an alkyl group containing from eight to fourteen carbon atoms, n is a small whole number from one to two, and A is an aromatic nucleus, to form an acidic, partial ester of phosphoric acid, and (2) forming a mixture of the acidic, partial ester obtained by step (1) and a quantity of acetic acid from about fifty percent to about one hundred percent equivalent to said acidic, partial ester on the basis of neutralization number, and (3) reacting the mixture formed in step (2) with an alkaline earth metal compound selected from the group consisting of an oxide and a hydroxide, at a temperature between about 400 F. and about 500 F., the amount of said metal compound being at least sufficient to neutralize the acetic acid and the acidic, partial ester.

Lubricant Composition, Patent 2,790,768 (F. C. McCoy, assignor to The Texas Co.) A composition of matter consisting essentially of a mineral lubricating oil, 4 to 4.5% by weight based on said oil of a mixture of an alkaline earth metal mahogany sulfonate and a dithiophosphate selected from the group consisting of zinc and barium hexyl and methyl cyclohexyl dithiophosphates, said mixture acting to lower the flash point of said mineral lubricating oil alone by at least 15 F., and an amount up to 2.5 ppm of a liquid dimethyl silicone polymer effective to raise the flash point of said mineral lubricating oil containing said mixture by at least 15 F.

Greases Prepared by Alkali Fusion of Fatty Materials, Patent 2,790,769 (A. J. Morway and A. Beerbower, assignors to Esso Research & Engineering Co.) The process of preparing lubricating greases adapted for lubrication at high temperatures which comprises saponifying in a mineral lubricating oil in grease-making proportions a saponifiable material selected from the group consisting of (1) mixtures consisting of saturated high molecular weight fatty acids and glycerine, (2) mixtures consisting of unsaturated high molecular weight fatty acids and glycerine, said glycerine being present in an amount corresponding to that present in the glycerides of said fatty acids and (3) glycerides of high molecular weight fatty acids, with an amount of sodium hydroxide which is about 100 to 125% more than that required to saponify said material, heating the resulting mixture to complete the saponification of the fatty acids, continuing heating at a temperature of about 530 to 570 F. until hydrogen gas evolution recedes, and then cooling to obtain said lubricating grease.

BOOK REVIEW

(Continued from p. 288)

of 0.5. In equation (8.9), the factor 2 outside the square-root sign is superfluous. On page 201, the ratio (friction defect)/(velocity velocity) should read (velocity defect)/(friction velocity). In the fifth equation on p. 203, a square-root sign is missing. In the last equation on the same page, V^* and k_1 are interchanged. Equation (8.43) is wrong, so is equation (10.32 a). In equation (8.52), the constant −0.249 should be changed to −1.024. In equation (10.11), Θ_2'/Θ_2 should read Θ_2'/Θ_1. Exponents are either left out or misprinted in equations (8.36), (10.37) on p. 256, (10.57), and the first equation on p. 175. Incidentally, two different equations are both numbered (10.37). Greek letters are misprinted on pp. 206 and 299. Parentheses are left out of the last equation on p. 208, and the fifth line from the bottom of p. 255.

In short, this book does not appear to be one of the best written and best printed on the subject in the English language.

Advertiser's Index

Baroid Div., National Lead Co. . 286
Cities Service Oil Co. 290
Farval Corp. . . . Inside Front Cover
Hodson Corp. . . . . Rear Cover
King, O. L. Co. 285
Magie Bros. Oil Co. 315
Trabon Engineering Corp.
Inside Rear Cover

TRABON

CENTRALIZED LUBRICATING SYSTEMS

Giant ore bridge buckets dig and load 17% more with Trabon lubrication

Now, lubricating this giant ore bridge bucket is simple and economical! All a man does is to connect a very inexpensive grease gun to a Trabon heavy duty feeder. All 40 bearings then receive the exact measured amount of grease they need in a matter of minutes. Downtime for lubrication is cut from 45 minutes to less than 5 minutes. Digging and blast furnace loading time is increased 17% each 8-hour day. Lubrication is now safe, dependable and positive since Trabon Centralized Lubrication Systems were installed at this Midwestern steel plant three years ago on three giant ore bridge buckets. Write today for further information.

Close up shows Trabon feeder system operating on one of three similarly equipped ore bridge buckets. All industry relies on Trabon for positive lubrication under rugged conditions.

Trabon

Trabon Engineering Corporation

28787 Aurora Road • Solon, Ohio

Centralized OIL AND GREASE SYSTEMS *Motorlift* CIRCULATING OIL SYSTEMS

TRUCK AND DOLLY CASTER LUBRICATION

NOMELT lubricant recommended where ambient temperatures are encountered requiring a heat resistant lubricant that will not melt at above normal temperatures.

It is excellent for truck and dolly caster lubrication. May be applied to the swivel and wheel bearings as used on assembly line buggies, oven buggies, etc.—Same lubricant for all requirements.

Lubrichanics by Hodson

NOMELT® LUBRICANT

Unqualifiedly Recommended for
High Heats—Low Temperatures—Heavy Loads

The HODSON CORPORATION
Lubrication
5301-11 West Sixty-Sixth Street
CHICAGO 38, ILLINOIS

7-L-58

Printed in U.S.A.